Sub-30ms real-time, free-breathing cardiac cine with VISTA sampling and SPIRiT reconstruction: A comparison with conventional segmented cine

Samuel T Ting[1], Yu Ding[1], Hui Xue[2], Shivraman Giri[3], Ning Jin[3], Rizwan Ahmad[1], and Orlando P Simonetti[1]

[1]*The Ohio State University, Columbus, OH, United States,* [2]*National Heart Lung and Blood Institute, Bethesda, MD, United States,* [3]*Siemens Healthcare, Chicago, IL, United States*

Purpose: Combined with Variable density Incoherent Spatiotemporal Acquisition (VISTA, [1]), SPIRiT [2] reconstruction can provide an avenue for highly accelerated real-time, free-breathing cardiac imaging. However, practical clinical implementation requires efficient optimization algorithms and a pathway for direct reconstruction on the scanner in a time efficient manner. We achieve this by using the Fast Iterative Shrinkage Thresholding Algorithm (FISTA, [3]) to reduce the computational cost of SPIRiT [4], and by implementing this technique using GPU processing within the Gadgetron framework [5]. We demonstrate a clinically practical implementation of real-time cine accelerated to rate 15 with good image quality and volumetric parameters that closely match those obtained using conventional segmented cine techniques.

Reconstruction: SPIRiT reconstruction was implemented within the Gadgetron framework using a 7x7 kernel. The VISTA sampling pattern was used to provide sufficient spatiotemporal incoherence for subsequent reconstruction. Spatiotemporal ℓ_1-regularization within the 3D wavelet domain was implemented to take advantage of this sampling, allowing reconstruction of highly undersampled data. FISTA enables highly efficient iterative optimization by eliminating the need for a line search along the gradient direction, both reducing per-iteration computation time and improving convergence [4]. All real-time data were reconstructed within the Gadgetron framework using an Intel Core i7 workstation with 64GB system memory and an NVIDIA GeForce GTX Titan with 6GB memory. Coil compression from 32 to 20 channels was used to further reduce computation time. A sliding window view-sharing across three frames and subsequent GRAPPA reconstruction using a 2x11 kernel was used as an initialization for the FISTA algorithm. The GRAPPA and SPIRiT kernels were estimated from the temporal average of all frames. A minimum change in the cost function of 1e-4 was used as a stopping criterion.

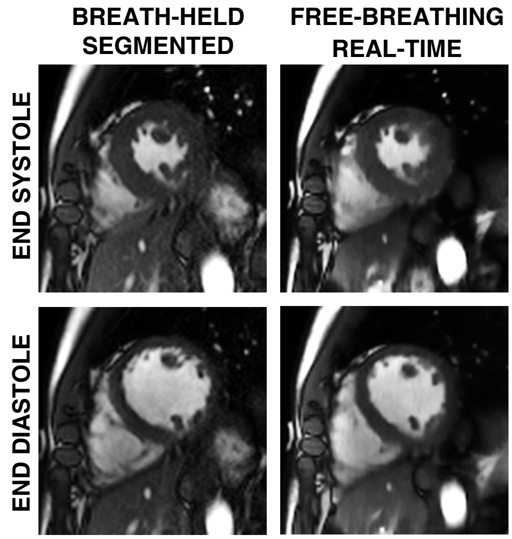

Figure 1: Example **breath-held** segmented (**left**) and **free-breathing** real-time (**right**) images at end systole (**top**) and end diastole (**bottom**).

REAL-TIME			
EDV (mL)	ESV (mL)	SV (mL)	EF
119.23 ± 14.32	52.82 ± 6.32	66.42 ± 14.83	55.26% ± 6.73%
SEGMENTED			
119.82 ± 16.04	52.15 ± 6.82	67.67 ± 17.22	55.89% ± 7.62%
p = 0.598	p = 0.487	p = 0.330	p = 0.406

Table 1: Summary of volumetric parameters (mean ± std. dev.). P-values show no significant difference between breath-held segmented data and breath-held real-time data.

Volunteer Study: Short axis stacks (10-12 slices) were acquired at rest from six healthy volunteers (Siemens, Tim Trio, 3T, 32 channels) using (1) a conventional segmented cine technique (breath-held, 40 phases, acceleration rate: 3, 15 segments, 10 lines/segment) and (2) our real-time technique (free-breathing, 40 phases, acceleration rate: 15). Acquisition parameters common to both techniques were as follows: FOV: 240mm x 240mm, slice thickness: 8mm, matrix size: 150x160, BW: 1488Hz, TR/TE: 2.8ms/1.26ms, FA: 50, temporal resolution: 28.2ms. To eliminate the need for registration between slices, a third series was acquired using the real-time technique during breath-hold for calculation of volumetric parameters. Datasets were visually scored by a qualified reader for image quality (1: nondiagnostic, 2: poor, 3: adequate, 4: good, 5: excellent), temporal fidelity of wall motion (1: nondiagnostic, 2: poor, 3: adequate, 4: good, 5: excellent), and artifact level (1: nondiagnostic, 2: severe, 3: moderate, 4: mild, 5: minimal). End-expiration diastolic and systolic phases were estimated from breath-held series (segmented and real-time), and endocardial contours were drawn within Argus (Siemens) and used to estimate end diastolic volume (EDV), end systolic volume (ESV), stroke volume (SV), and ejection fraction (EF).

	BREATH-HELD		FREE-BREATHING
	SEGMENTED	REAL-TIME	REAL-TIME
ARTIFACT	4.33 ± 0.52	4.00 ± 0.00	3.67 ± 0.52
TEMPORAL FIDELITY	4.50 ± 0.55	3.50 ± 0.55	3.83 ± 0.41
IMAGE QUALITY	4.50 ± 0.55	4.00 ± 0.00	3.83 ± 0.41

Table 2: Scoring of artifact, temporal fidelity, and image quality (mean ± std. dev.) for all volunteers.

Results: Figure 1 shows breath-held segmented cine images and free-breathing real-time images at end diastole and end systole. Paired t-test results show no significant differences in EDV, ESV, SV, and EF between breath-held segmented and breath-held real-time series (Table 1). Table 2 shows visual scoring (mean and standard deviation) for all datasets. While all scores were at least adequate in all real-time series (including free-breathing), paired t-test results indicate significant differences (1) for all metrics between the breath-held segmented and free-breathing real-time series (p=0.025 for all comparisons) and (2) in artifact between breath-held segmented and breath-held real-time datasets (p=0.012). No significant differences in any scores were observed between free-breathing and breath-hold real-time images. Average reconstruction time for each 40-frame image series within the Gadgetron framework was reduced to 56.2 seconds using FISTA from a previously reported 20 minutes using NLCG techniques [1] within MATLAB. With the use of multiple GPUs, we expect additional reduction in computation time.

Conclusion: Combined with VISTA and spatiotemporal regularization, the FISTA implementation of SPIRiT within the Gadgetron framework provides a clinically practical avenue for highly accelerated, real-time, free-breathing cardiac imaging in terms of overall image quality, quantification of volumetric parameters, and reasonable reconstruction time.

References: [1] Ahmad R. et al. ISMRM DSIR Workshop, 2013. [2] Lustig M. et al. Mag Res Med. 2010; 64(**2**):457-71. [3] Beck A. et al. SIAM J Imag. Sci. 2009; 2(**1**):183-202. [4] Ting ST. et al. Proc. ISMRM, 2013. p. 3813. [5] Hansen MS, et al. Mag Res Med. 2013; 69(**6**):1768-76.