Cardiac free-breathing balanced SSFP cine sequences: Radial vs. Cartesian k-space reconstruction

L. Mannelli[1], M. B. Srichai-Parsia[2], D. Kim[1], X. Sinani[2], R. Hiralal[1], and R. P. Lim[1]
[1]Radiology, New York University, New Nork, New Nork, United States, [2]Radiology, Bellevue Hospital Center, New York, New York, United States

Introduction
Breath-hold (BH) segmented balanced steady state free precession (SSFP) imaging with Cartesian k-space reconstruction is routinely used for quantification of left and right ventricle (LV and RV) systolic and diastolic volumes, ejection fraction (EF), and for evaluation of segmental wall motion [1-3]. However, patients who are unable to breath-hold or who have significant arrhythmias can pose a difficult challenge for segmented SSFP cine imaging. There are several possible strategies to improve image quality depending on scanner capabilities and available software. Real-time cine imaging is a commonly used alternative cardiac MR acquisition technique for such patients [4]. Radial k-space reconstruction, which includes a relative oversampling of the center of k-space, may offer potential benefit over a Cartesian approach [5]. In this study, we compare Cartesian versus Radial k-space reconstruction for a free-breathing real-time balanced SSFP (true fast imaging with steady-state precession, True-FISP, Siemens) sequence to quantify LV and RV volumes and EF.

Methods
Left and right ventricular volume and function studies were performed in 15 consecutive patients (9 male and 6 female, mean age 61, range 19 to 88 y/o). The reason for the cardiac MRI was: viability (6), ascending aorta aneurysm (1), non-compaction (1), stress test (1), source of emboli (2), cardiac mass (1), Arrhythmogenic Right Ventricular Dysplasia (1), aortic valve replacement (1), ventricular septum defect (1). Three different ECG-gated True-FISP cine sequences were acquired in short axis views through the heart using a 1.5T scanner (Avanto, Siemens): free-breathing single shot with radial k-space reconstruction (TR/TE 77.1/1.2 ms, flip angle 60°, FOV 250x250 mm, acquisition time 39 sec, 13 slices, voxel 3.9x3.9x8 mm, slice thickness 8 mm, distance factor 25%, averages 1, Bandwidth 1302 Hz/Px), free-breathing single shot with Cartesian k-space reconstruction (TR/TE 79.2/1.2 ms, flip angle 60°, FOV 241x350 mm, acquisition time 83 sec, 13 slices, voxel 6.7x5.5x8 mm, slice thickness 8 mm, distance factor 25%, averages 1, Bandwidth 1302 Hz/Px, parallel imaging GRAPPA acceleration factor 2), and breath-hold (BH) segmented acquisition with Cartesian k-space reconstruction (TR/TE 39.3/1.3 ms, FOV 266x340 mm, TA 11 sec per slice, parallel imaging GRAPPA acceleration factor 2). 13 slices were acquired for each sequence. The free-breathing Radial and Cartesian acquisition parameters were matched to maintain similar temporal resolution. For the radial and Cartesian sequences the temporal resolution was 77 ms and 79 ms, respectively. The segmented Cartesian acquisition had temporal resolution of 45 ms. Ventricular cavities were manually segmented at end-diastolic and end-systolic phases by a single radiologist. The BH sequence was used as the reference standard, and Bland-Altman analysis was performed to evaluate the free-breathing sequences.

Results
With the BH sequence, mean±SD LV EF was 53.4±20% (range 22.3% - 73.6%), and RV EF was 51.6±21% (range 7.8% - 72.9%). With the free breathing Cartesian k-space reconstruction sequence the LV EF was 51.7±24% (range 16.6% - 88%), and the RV EF was 49.2±20% (range 11.6% - 70.5%). With the free-breathing radial k-space reconstruction sequence LV EF was 53.2±21% (range 24.1% - 81%), and the RV EF was 46.9±17% (range 14% - 72.6%). RV and LV end systolic (ES) and end diastolic (ED) Volumes (V) are reported in table 1. Representative images from a patient with ischemic heart disease are shown in Figure 1.
Bland-Altman analysis between the BH and the free-breathing Cartesian k-space reconstruction demonstrated the measured bias for LV EF was 2.7% and the 95% limits of agreement (LOA) were -12.9 to 18.3%, the bias for RV EF was 8.6% and the 95% LOA were -15.8% to 32.6%. Between the BH and the free-breathing radial k-space reconstruction, the measured bias for LV EF was -0.8% and the 95% LOA were -8.3 to 7.5%, the bias for RV EF was 5.9% and the 95% LOA were -23.1 to 33.7%. Bland-Altman analysis for EDV and ESV of the RV and LV are shown in table 2.

Table 1: Mean LV and RV end diastolic volumes (EDV) and end systolic volumes (ESV)

	BH Cartesian	Free breathing Cartesian	Free breathing Radial
LV EDV	167±76 ml	154±60 ml	165±74 ml
LV ESV	93±68 ml	88±66 ml	91±71 ml
RV EDV	154±79 ml	126±59 ml	132±69 ml
RV ESV	85±66 ml	76±56 ml	77±56 ml

Table 2 Bland-Altman analysis between the BH and free breathing acquisitions

		Bland-Altman Bias	LOA
LV EDV	BH Cartesian vs FB Cartesian	8.90%	-42.3 to 60.1%
LV EDV	BH Cartesian vs FB Radial	4%	-47.4 to 39.3%
LV ESV	BH Cartesian vs FB Cartesian	0.40%	-23.7 to 22.8%
LV ESV	BH Cartesian vs FB Radial	-3.80%	-29 to 21.4%
RV EDV	BH Cartesian vs FB Cartesian	27%	-18.1 to 72.1%
RV EDV	BH Cartesian vs FB Radial	19.50%	-31.6 to 70.6%
RV ESV	BH Cartesian vs FB Cartesian	4.40%	-26.5 to 35.3%
RV ESV	BH Cartesian vs FB Radial	4.90%	-24.8 to 34.6%

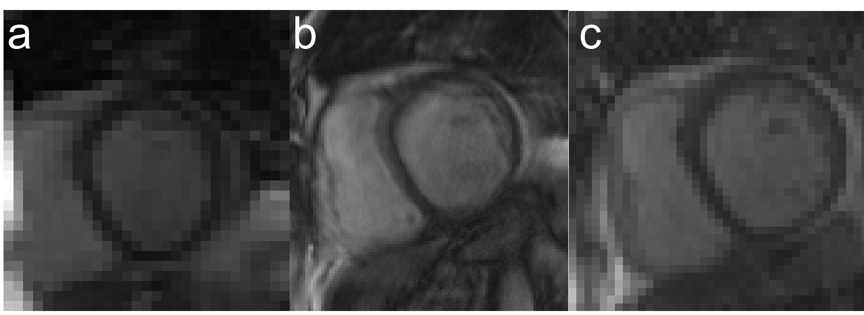

Figure 1: 60 y/o man with recent myocardial infarction, supra ventricular tachycardia, and inability to breath hold. Selected cine TrueFISP images from: a) free-breathing single shot with Cartesian k-space reconstruction. b) breath-hold segmented acquisition with Cartesian k-space reconstruction (acquisition time 11 sec) and c) free-breathing single shot with radial k-space reconstruction.

Discussion and Conclusions
In clinical practice, patients undergoing cardiac MR examination frequently have difficulty complying with breath-holding and/or have arrhythmias that limit diagnostic evaluation with segmented BH acquisitions, particularly for assessment of ventricular volumes, function and segmental wall motion abnormalities. Non breath-hold, real-time cine acquisitions have the potential to significantly reduce overall scan time and provide quantitative information that is comparable to segmented BH cine acquisitions, particularly useful for difficult or critically unwell patients. In our experience, the use of free-breathing true-FISP with radial k-space reconstruction provided more accurate measurements of ventricular volumes and ejection fraction when compared to those obtained with free-breathing true-FISP with Cartesian reconstruction. Radial trajectories have several advantages over Cartesian trajectories for dynamic MRI. In contrast to Cartesian trajectories, spatial resolution in radial trajectories is mainly determined by the imaging FOV, and there is only a limited tradeoff between spatial resolution and number of views. Furthermore, due to oversampling of the central k-space region, radial trajectories are more robust to motion artifacts [5]. Exploring temporal parallel acquisition techniques, parallel imaging with dedicated multi-channel receive coils, could engender further improvements in real time cine temporal and/or spatial resolution. Future work including incorporation of a compressed sensing approach for clinical evaluation is planned. Free-breathing cine true-FISP imaging with radial k-space reconstruction produces LV and RV volumes as well as EF measurements which are more accurate compared to those obtained with free-breathing true-FISP imaging with Cartesian reconstruction.

References
[1] Malayeri AA, et al. 2008, J Magn Reson Imaging 28(1):60.
[2] Kunz RP, et al. 2005, J Magn Reson Imaging 21(2):140-8.
[3] Hunold P, et al. 2004, J Magn Reson Imaging 20(3):506-11.
[4] Hansen MS, et al. 2006 Magn Reson Med 55(1):85-91.
[5] Jung H, et al. 2009, [Epub ahead of print].