Feasibility of 5-Minute Comprehensive Cardiac MR Examination Using Highly Accelerated Parallel Imaging and Compressed Sensing

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INTRODUCTION: The feasibility and initial evaluation of a 5 min comprehensive cardiac examination protocol using highly accelerated parallel imaging including cardiac function (CINE), first-pass myocardial rest perfusion (PERF), coronary artery anatomy (CAI) and myocardial viability via late gadolinium enhancement (LGE) was recently reported[1,2]. Comparatively high quality results were obtained in a few breath-holds (BH). Challenges for this protocol include competing requirements of high spatial resolution, immunity to physiologic motion, high signal-to-noise ratio (SNR), and practical total examination time [3]. For example, PERF and LGE imaging demonstrate relatively low SNR compared to 2D approaches due to noise amplification caused by high acceleration factors. Combination of parallel imaging with compressed sensing enables higher accelerations for cardiac imaging without sacrificing SNR [4]. We have recently developed a joint reconstruction technique for undersampled radial acquisition named k-t RAdial SParse-Sense (k-t RASPS), which promises further improvements in acquisition time and whole heart coverage with high temporal/spatial resolution. In this study, we have incorporated dynamic 4D stack-of-stars hybrid radial acquisitions with k-t RASPS reconstruction into the 5-min protocol, and compared the k-t RASPS technique with the previous 3D highly accelerated approach (PAT) for PERF, CINE and LGE imaging

METHODS AND MATERIALS: All MRI examinations were performed on a whole-body 1.5T scanner (Siemens AG, Erlangen, Germany) with a high performance gradient system (max. amplitude: 40 mT/m, max. slew rate: 200 mT/m/ms) and a 32-element cardiac coil array (InVivo, Gainesville, FL, USA). Following informed consent, 2 patients (1 male, mean age 37) and 2 healthy volunteers (2 M, mean age 26) were recruited. In order to allow fair comparison between the approaches, the RASPS and PAT acquisitions were alternated in terms of which acquisition was performed first for each imaging technique (PERF, CINE and LGE). Two contrast injections for PERF were used with a single dose each (0.1mmol/kg) of gadolinium-DTPA (Berlex Magnevist, Schering AG) at 5ml/s followed by a saline flush (20ml at 5ml/s), for a cumulative 0.2 mmol/kg dose of gadolinium contrast to ensure sufficient enhancement for the final LGE scans. The time between the initial contrast injection and LGE acquisitions was approximately 10-15 minutes. In-plane radial k-space sampling and though-plane Cartesian encoding was used in all imaging acquisitions for RASPS, The key parameters are summarized in Table 1. **Perfusion**: A 3D saturation prepared T1-weighted Turbo FLASH sequence with radial acquisition in the short-axis plane was performed: readout 128 pixels, 200 spokes, 10 spokes per partition, slice resolution 50%, slice partial Fourier 6/8, temporal resolution ~300ms. Each entire 3D measure was obtained at 1-RR intervals, repeated for 60 measures. **Cine imaging**: A 3D radial SSFP sequence in short-axis plane was performed: readout 128 pixels,200 spokes, slice partial Fourier factor 6/8, 10 spokes per partition, temporal resolution 22ms, continuously acquired frames with 30~40 imaging frames per R-R interval, dependent on heart rate. **Viability**: Similar approach and parameters were used as for CINE, except that a non-selective inversion recovery pre-pulse was performed to increase T1 contrast between normal and infarcted myocardium without specifically defining the precise null time of normal myocardium. k-t RASPS reconstruction was implemented off-line using custom software in MATLAB (Mathworks, MA), by incorporating the non-uniform FFT (NUFFT) operator into the original k-t RASPS reconstruction to regrid radial k-space data. The total variation along the temporal domain was employed as sparsifying transformation.

RESULTS: All subjects successfully completed the sequential RASPS and PAT protocols. Figure 1, 2 and 3 show typical results and comparisons of PERF, CINE and LGE imaging between RASPS and PAT. RASPS results in good image quality while allowing whole-heart isotropic data with larger slice number and thinner slice thickness whole heart coverage is achieved using RASPS as compared with PAT.

CONCLUSIONS: This work demonstrated that comparable image quality for 4D PERF, CINE, and LGE acquisitions can be achieved at increased whole heart coverage using the proposed RASPS approach. Further evaluation of the RASPS approach is currently in progress, including assessment of the feasibility and clinical efficacy in a patient cohort with cardiac disease. CAI studies with compressed-sensing acceleration are also planned.

REFERENCE: [1]Xu et al., ISMRM 2009; [2]Xu et al., ISMRM 2011; [3]Foo, T.K., et al. Radiology, 2005; [4] Otazo R et al.,MRM 2010.

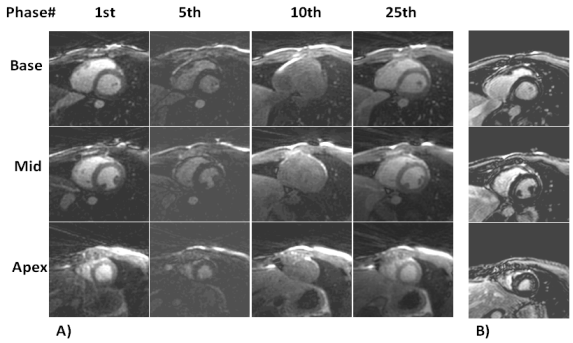

Fig. 3: **A)** Selected short-axis LGE MR images from base to apex obtained in a healthy subject (22 yrs,160lb,male). Each row shows images in same slice position but with different TI values from different cardaic phases. The images illustrate the TI dependence of the contrast from different tissues with different T1s. **B)** shows the correspongding 3D LGE using PAT. A single phase during mid diastole was acquired and an additional scout was needed to determine the precise null time of normal myocardium.

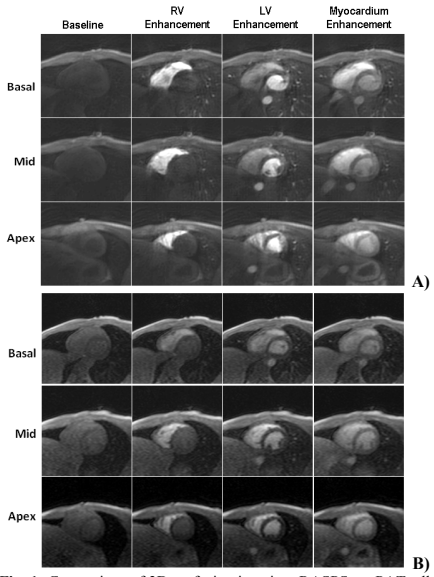

Fig. 1: Comparison of 3D perfusion imaging: RASPS vs. PAT, all acquired in a single BH. A) selected 3 of 36 slices using RASPS and B) selected 3 of 10 slices using PAT from base to apex show the baseline, RV/LV and myocardium enhancement.

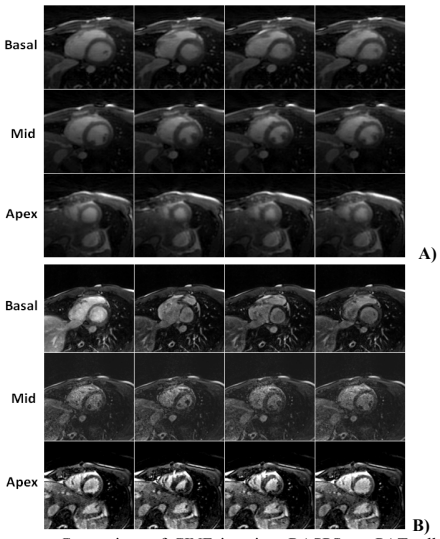

Fig. 2: Comparison of CINE imaging: RASPS vs. PAT, all acquired in a single BH. A) RASPS (3/40 total slices) and B) PAT (3/20 total slices) from base to apex, showing cardiac contraction.

Type	Perfusion		CINE		LGE	
	RASPS	**PAT**	**RASPS**	**PAT**	**RASPS**	**PAT**
Sequence	FLASH	FLASH	SSFP	SSFP	SSFP	**SSFP**
Reconstruction	RASPS	TGRAPPA	RASPS	TGRAPPA	RASPS	**GRAPPA**
Matrix	128x200x36	76x128x10	128x200x40	109x176x20	128x200x40	**144x144x20**
Voxel Size	2.8x2.8x2.8	4.4x2.6x8	2.8x2.8x2.8	3.1x1.9x5	2.8x2.8x2.8	**2.4x2.4x6**
Acceleration R	200/10	4 x 2	200/10	4 x 2	200/10	**3 x 2**
TI/TR/TE (ms)	~110/2.2/1.1	130/270/0.9	-/2.2/1.1	-/3.1/1.1	~/2.2/1.1	**~250/3.0/1.**
BW(Hz/pixel)	1502	1392	1502	915	1502	**500**
Flip Angle	**10**	**10**	**70**	**70**	**70**	**70**

Table 1: Typical imaging parameters used in RASPS and PAT approaches.