Feasibility of Dynamic 4D Whole Heart Viability Imaging Within a Single Breath-Hold Using Highly Accelerated Parallel Imaging and Compressed Sensing

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INTRODUCTION: Infarcted myocardium exhibits late gadolinium hyper-enhancement (LGE) and is usually imaged with an inversion recovery (IR) sequence [1]. The inversion time (TI) is typically set to null normal myocardial signal in order to maximize contrast between normal and infarcted myocardium. A multi-slice multi-planar 2D approach requiring multiple breath-holds (BH) is commonly used in routine clinical practice. An additional BH TI scout is utilized to determine the precise null time of normal myocardium in individual patients. The TI that is chosen and subsequently applied may not adequately null normal myocardium as 2D multi BH imaging proceeds over several minutes, due to gadolinium washout kinetics. Phase-sensitive inversion recovery (PSIR) imaging minimizes the need to precisely null normal myocardium [2], but as it requires two RRs per trigger, BH 3D PSIR LGE imaging is challenging to perform. Highly accelerated 3D LGE enables acquisition of all data at the same time point of contrast kinetics, which helps provide uniform suppression of the entire volume of normal myocardium within the imaged volume. However, this technique still requires a TI scout and demonstrates relatively low SNR compared to 2D techniques due to the high acceleration factor and IR pulse used [3]. We have recently developed a radial acquisition and k-t SPARSE SENSE [3] (k-t RASPS) technique that results in improved temporal and spatial resolution compared to the traditional 3D LGE techniques [4]. In this study, we evaluated the feasibility of whole heart dynamic 4D LGE imaging utilizing different TIs at different phases throughout the entire cardiac cycle within a single BH using 4D stack-of-stars radial acquisition and k-t RASPS without the use of a precise TI scout.

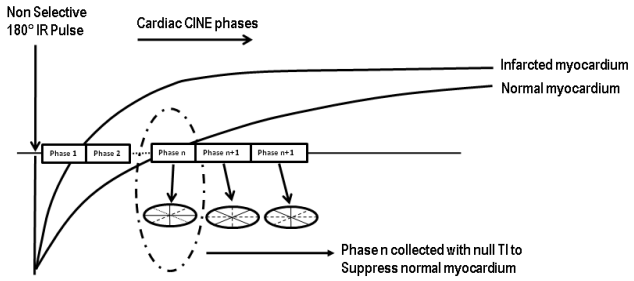

Figure 1: Schematic of the 4D CINE IR Pulse using radial k-space acquisitions. A nonselective IR pulse is used to improve T1 contrast. The T1 recovery curve is shown schematically for infarcted and normal myocardium as a function of the delay time to the inversion pulse. The radial sampling was rotated through the entire CINE cardiac phases. At optimal TI, the signal intensity of normal myocardium is near zero.

MATERIALS AND METHODS: All MRI examinations were performed on a whole-body 1.5T scanner (MAGNETOM Avanto, Siemens, Erlangen, Germany) equipped 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, Florida). Gd-DTPA 0.15 mmol/kg was administrated. Following informed consent, and institutional ethics approval, 2 healthy subjects (2 male, mean age 27) and two patients (1 male, mean age 39) with suspected cardiomyopathy were examined using 4D and 3D LGE approximately 10-15 minutes after contrast administration. As shown in Figure 1, an ECG gated and highly under-sampled 4D radial CINE SSFP sequence was developed with in-plane radial k-space sampling and though-plane Cartesian encoding. A non-selective inversion pulse was used to increase contrast between normal and infarcted myocardium. 10 radial spokes per slice were continuously acquired in each cardiac phase with the following imaging parameters: TR/TE 2.2/1.1ms, readout points 128, radial views 200 per slice, FOV 360x360 mm^2, slice number 40, slice partial Fourier 6/8, BW 1502Hz/pixel, 10 spokes per cardiac phase, temporal resolution 22 ms, spatial resolution 2.8x2.8x2.8 mm^3. Total number of cardiac phases were dependent on heart rate (mean = 36). The parameters used in 3D LGE were: IR prepared 3D SSFP sequence acquired during mid-diastole with GRAPPA factor 4 (PE) x2(3D),TR/TE 3.0/1.5 ms, matrix 144x144,slice number 20 with thickness 6 mm, FOV 360x360 mm^2,spatial resolution 2.4x2.4x6 mm^3,BW 500Hz/pixel. To determine the precise null time of normal myocardium, an additional TI scout was utilized for 3D LGE. K-t RASPS reconstruction was implemented off-line using custom software in MATLAB (Mathworks, MA) using a non linear conjugate gradient algorithm, and the total variation along the temporal domain was employed as sparsifying transform.

RESULTS: Figure 2 A) demonstrates 4D LGE at three short axis slices (base, mid and apical left ventricle) selected out of 40 total slices acquired at multiple phases (total 40) of the cardiac cycle. Dynamic motion of myocardium at different phases is depicted: phase 1 acquired during early systole, phase 5 acquired during systole and phase 25 acquired during mid-diastole. Excellent image quality with isotropic spatial resolution and whole heart coverage are achieved compared to B) 3D LGE using GRAPPA reconstruction, which was acquired during mid-diastole utilizing an additional TI scout acquisition to determine the precise null time of normal myocardium. In this example of 4D LGE (Fig 2A), the 5th phase demonstrates the optimal phase with regard to nulling of normal myocardium.

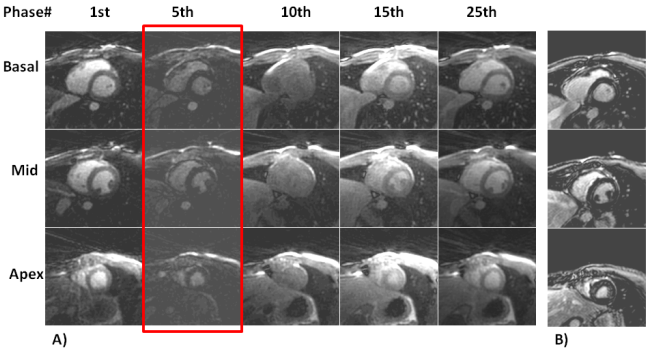

Figure 2: A) selected short-axis LGE images from base to apex obtained in a healthy subject (22 yrs,160lb,male) without suspected cardiomyopathy. Each row shows images in same slice position but with different TI values from different cardaic phases. The images illustrate the TI dependence of the contrast from different tissues with different T1s. **B)** shows the correspongding 3D LGE using highly accelerated parallel imaging. A single phase during mid diastole aquired and an additional TI scout was needed to determine the precise null time of normal myocardium.

CONCLUSIONS: With our proposed approach, multiple TI-whole heart inversion recovery LGE imaging (4D LGE) can be performed with good nulling of normal myocardium within a breath-hold without the need for a TI scout. Relatively high temporal resolution and spatial resolution were achieved in this study with the combination of radial sampling, parallel imaging and compressed sensing reconstruction. An approximate trigger delay and reduced phase number make the overall acquisitions during diastole possible. Further evaluation of RASPS compared with standard 2D or 3D LGE imaging approaches including efficacy in a clinical cohort with cardiac disease is underway.

REFERENCE: [1]Simonett OP,et al.,Radiology,2001;[2]Kellman P,et al. MRM 2002; [3]Otazo R et al. MRM 2010; 64:767-776. [4]Xu J, et al, ISMRM 2010;