Highly Accelerated Free-breathing 4D Cardiac Imaging with CIRCUS Acquisition

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INTRODUCTION

4D cardiovascular MRI applications typically require prolonged scan times and suffer from artifacts due to physiological motion. Compressed sensing (CS) and its combination with parallel imaging (PI) have recently emerged as valuable tools for accelerating MRI acquisitions by reconstructing images from undersampled k-space data. The required incoherent artifact in CS is usually achieved by theoretical random undersampling. In practice, pseudo-random undersampling is implemented. We recently proposed a novel pseudo-random undersampling strategy named CIRcular Cartesian UnderSampling (CIRCUS)[1], which integrates the desirable features of randomization and radial or spiral trajectories on a 3D Cartesian grid. CIRCUS allows easy implementation with flexible selection of pseudo radial, spiral, or random trajectories with specific degree of randomization. It provides high accuracy of image reconstruction and enables favorable interleaving features for 4D cardiovascular imaging. In this study, we will demonstrate highly accelerated 4D whole heart cardiac MRI using a joint multicoil CS reconstruction framework with CIRCUS.

MATERIALS AND METHODS

Data were acquired from healthy volunteers on a 3.0T MR scanner (GE Medical Systems, Milwaukee, WI) with an 8-channel cardiac coil during free breathing. A 3D gradient-echo sequence with CIRCUS (randomized golden-ratio pseudo radial sampling pattern[1]) was applied, with FOV=320mm, TR/TE=4.0/1.6ms, FA=45°, BW=±125kHz, slice thickness of 4mm, image matrix=256×160×32 (75% partial acquisition in k_y&k_z), and scan time of 200s. Retrospective cardiac and respiratory gating were applied. Cardiac phases were reconstructed with a temporal resolution of 40 ms (views per segments=10).

The interleaving features of CIRCUS allow us to evaluate image reconstruction at different acceleration rates, by retrospectively choosing respiratory gating efficiency (100%, 75%, 50% and 25% tested in this study) and effective scan time (200s and first 120s tested). The undersampled datasets were reconstructed using a multicoil CS reconstruction exploiting joint sparsity along the temporal dimension using a total variation constraint and the corresponding regularization parameters were empirically selected.[2,3] Image sharpness was evaluated on the left ventricle (LV) cavity-myocardium interface (averaged over 10 points around the LV at end-systolic, early- and end-diastolic phases).

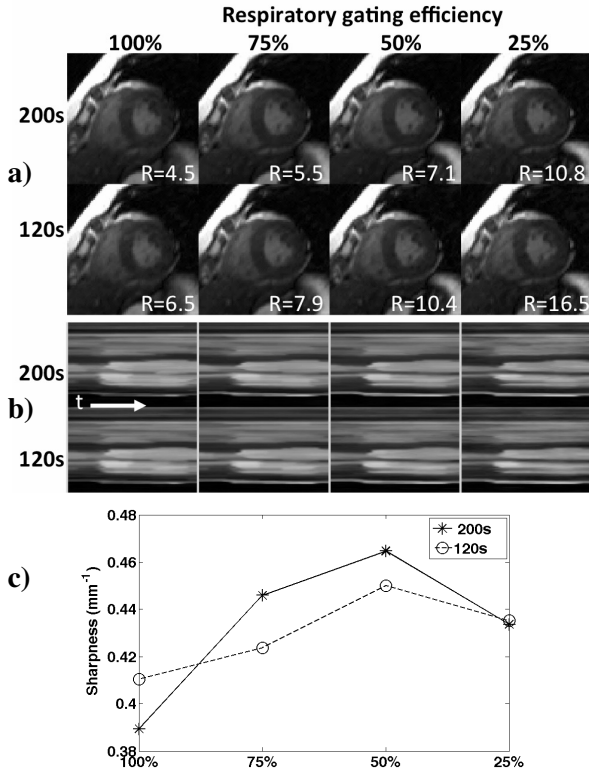

Fig.1 a) Reconstructed images at end-systole with different acceleration factors. **b)** Spatial-temporal profile crossing right and left ventricles (a horizontal line on **a**). **c)** Comparison of image sharpness.

RESULTS & DISCUSSION

Highly accelerated free-breathing whole heart 3D CINE imaging was successfully achieved by using the CIRCUS acquisition and the combination of multicoil CS reconstruction methods. Adequate image quality was obtained with various gating efficiencies and acceleration factors (Fig.1). Images obtained with an effective scan time of 200s and respiratory gating efficiency of 50% provided the best image quality, while those with an effective scan time of 120s and 50% gating efficiency also provided comparable results (Fig.2). Clinical cardiac functional measurements are achieved by acquiring 2D CINE images in multiple breath-holds (~5 mins), which often suffer from slice misregistration errors or result in non-diagnostic images in patients with impaired capability of suspending prolonged breathing. The proposed free-breathing 4D cardiac imaging (~2 mins) could be an attractive alternative for evaluating myocardial function with reliable and accurate functional measurements. Further evaluation of the proposed method is ongoing. This 4D technique has also been successfully tested for aorta, liver, and bowel imaging.

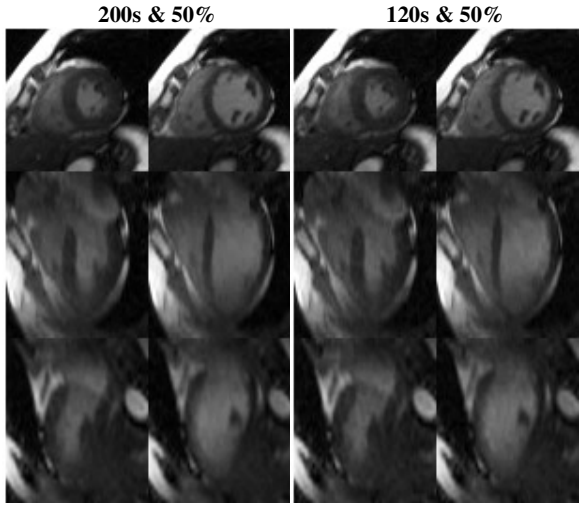

Fig.2 Reformatted short-axis, four- and two-chamber views at end-systolic and end-diastolic phases, with effective scan time of 200s (left block, R=7.1) and 120s (right block, R=10.4). The respiratory gating efficiency was 50%.

CONCLUSIONS

An effective k-space undersampling scheme has been successfully implemented and applied for highly accelerated 4D whole heart cardiac imaging.

REFERENCES 1. Liu J, et al, ISMRM, p3796. **2**. Otazo R et al. MRM 2010 Sep;64(3):767-76. **3**. Feng L et al, MRM 2013; Jul;70(1):64-74.