Fast-track cardiac diffusion tensor imaging with compressed sensing based on a novel circular Cartesian undersampling

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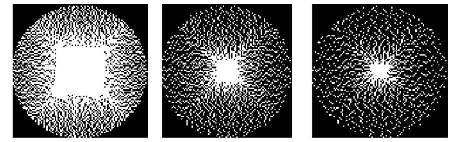

Fig. 1 k_y-k_z CIRCUS undersampling with acceleration factor of R=2, 4, and 6 respectively.

Introduction: In recent years, diffusion tensor MRI (DT-MRI) has been shown [1] to be extremely promising for characterizing the hierarchical microstructure of myocardium. The greatest challenge in the DT-MRI acquisition that severely limits its *in vivo* application has been the long scan times (i.e. a minimum of seven scans are required). Compressed sensing (CS) comprises algorithms that recover data from under-sampled acquisitions, and has been reported [2] to reduce data acquisition time in MRI without requiring extra dedicated hardware. In this study, we investigate the feasibility of applying a novel three-dimensional (3D) Cartesian under-sampling scheme and compressed sensing reconstruction to the DT-MRI of an excised rat heart. We also quantify the effect of under-sampling on global DT-MRI-derived parameters.

Materials and Methods: MRI: Imaging of an excised rat heart was performed on a 7T Agilent horizontal MR scanner equipped with a 400mT/m gradient system using a 38mm diameter ^{1}H quadrature birdcage coil. To avoid susceptibility artifacts and proton signal from Formalin, the heart was suspended in a 15mm diameter cylinder filled with Fomblin. The imaging parameters were: A 3D spin echo sequence, T_R/T_E = 500/20ms, matrix size = 97×97, resolution = 0.160mm (isotropic), nominal b-value = 1000s/mm^2. The optimized scheme of 12 gradient directions [3] was used. An additional non-weighted (b=0) dataset was acquired. Total imaging time: ~16h.

Compressed sensing: A novel CIRcular Cartesian UnderSampling (CIRCUS) method was proposed in [4] to provide efficient variable-density sampling patterns on k_y-k_z plane of the 3D Cartesian acquisition. The proposed under-sampling patterns were shown to be well-suited for CS reconstruction, providing high accuracy of image reconstruction. In this study, a randomized CIRCUS pattern with a golden-ratio profile and a non-linear shift was generated and applied retrospectively to the fully-sampled cardiac DT-MRI data set, with an acceleration factor of 2, 4 and 6 (sampling patterns are shown in Fig. 1). All under-sampled data were reconstructed with CS algorithm [5] (L_1-norm and total variance).

Data analysis: Diffusion tensor data was reconstructed using the FSL software package [6]. The entire (segmented) left-ventricular wall was analyzed. Maps of fractional anisotropy (FA), mean diffusivity (MD), and helix angles (HA) were computed for the fully-sampled and under-sampled datasets using custom-made software in Matlab (Mathworks, Natick, MA). To evaluate the accuracy of under-sampling, root mean square errors (RMSEs) of FA, MD, and HA were estimated between the full-sampled and the accelerated data-sets.

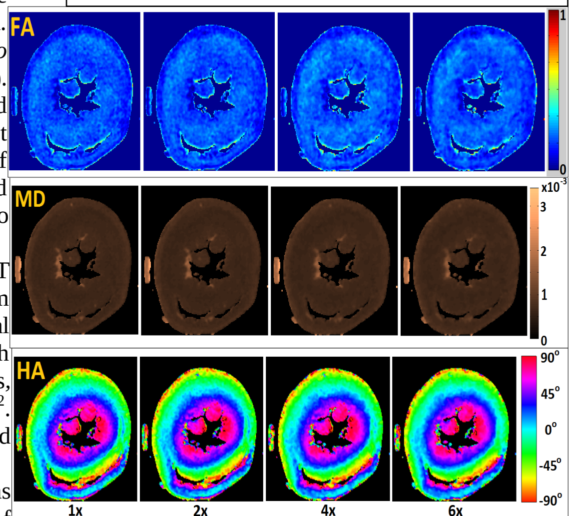

Fig. 2 FA (top), MD (middle) and HA (bottom) of the full and under-sampled data. The unit of MD is mm^2/s.

Table 1 RMSE of FA, MD, and HA for the 3 acceleration factors.

	FA	MD (10^{-5} mm^2/s)	HA (°)
2x	0.0157	1.2813	2.3933
4x	0.0248	2.0642	4.1952
6x	0.0283	2.5137	4.5671

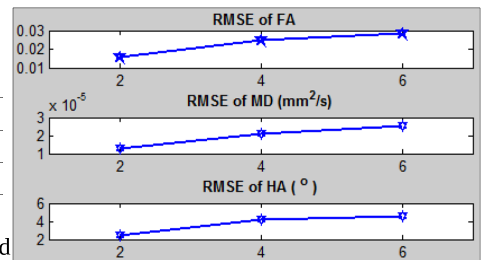

Fig. 3 RMSE of FA (top), MD (middle) and HA (bottom) of the under-sampled data.

Results and Discussion: Fig. 2 depicts maps of FA (1st row), MD (2nd row), HA (3rd row) for the fully (1x), 2- (2x), 4-(4x), and 6-fold (6x) under-sampled datasets. The quality of the maps produced by the under-sampled data is comparable to the maps obtained from the fully-sampled data. Table 2 (and Fig. 3) summarizes the RMSE for all DT-MRI-derived parameters and acceleration factors. We find that even though the RSME values increase with the acceleration factor, the loss of information is minor. We conclude that essential information on cardiac diffusion properties, such as diffusion anisotropy, mean diffusivity, and primary orientation, is preserved up to an acceleration factor of 6.

Conclusions: We have demonstrated that CS using novel CIRCUS can be used to shorten acquisition times of cardiac DT-MRI without significant impairment of accuracy. In this study, under-sampling was performed retrospectively rather than during acquisition. However, there is work in progress to implement the under-sampling directly on the MR scanner, and, thus, fully exploit the temporal merit of this technique.

References: [1] Garrido L et al. *Circ Res* 1994;74:789, [2] Jung H et al. *Magn Reson Med* 2010;63:68, [3] Papadakis NG et al.*J Magn Reson* 1999;137:67, [4] Liu J, et al ISMRM 2013, 2683 (submitted), [5] Lustig M, et al. *Magn Reson Med* 2007;58:1182, [6] FSL Webpage: fsl.fmrib.ox.ac.uk/fsl.

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