In vivo 3D high resolution cardiac diffusion weighted MRI: a motion compensated diffusion-prepared balanced steady-state free precession approach

Christopher T Nguyen1,2*, Zhaoyang Fan1, Behzad Sharif3, Yi He3, Rohan Dharmakumar1, Daniel S Berman1, Debiao Li1,2

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Background
Cardiac diffusion-weighted MRI has the potential to identify acute myocardial infarction, myocarditis, and myocardial fibrosis [1-3]. The aim of this study was to implement and optimize a novel application of diffusion-prepared bSSFP to perform in vivo cardiac diffusion-weighted MRI.
Methods

Diffusion-prepared sequences have the flexibility to diffusion encode with a multi-shot image readout. The diffusion preparation was optimized to reduce sensitivity to cardiac bulk motion with second order motion compensation (M1M2). The image readout consists of a 3D centric phase encoded segmented bSSFP acquisition that incorporates a prospective navigator. Ten healthy subjects were scanned twice (once in the beginning and at the end) on a 1.5T system (Siemens Avanto) using the proposed technique (TR/TE = 3.4/1.3 ms, FOV = 256 × 256 mm², α = 110°, 160 × 160 matrix, 10 mm slice thickness, 4 slices with 20% oversampling, 40 mm 3D slab, 5 linear ramp-up, b = 450 s/mm², Gdiff = 40 mT/m). Diffusion preparation was applied in the diastolic phase with (TEprep = 115 ms) and without (TEprep = 45 ms) M1M2.
using 3 orthogonal directions under varying off-resonance conditions. Trace apparent diffusion coefficient (trADC) maps and the left ventricular (LV) trADC were calculated. For each slice, the LV was segmented into six AHA segments. Statistical significance was tested using two tailed paired t-test for two mean comparisons and one-way ANOVA for multiple means comparisons.

Results
M1M2 diffusion-prepared scans resulted in LV trADC values of $1.5 \pm 0.4 \times 10^{-3}$ mm$^2$/s that were reproducible yielding no statistical differences ($p = 0.54$). Regional differences between six AHA segments were not statistically significant across all subjects ($p = 0.97$). M1M2 diffusion-prepared images showed no ghosting artifacts and/or signal fallout. Under certain substantial off-resonance frequencies (e.g., +200 Hz), the proposed method failed in yielding both T2prep and DW images when bSSFP-related banding formed. The non-motion compensated diffusion-prepared scans yielded LV trADC values of $6.6 \pm 0.9 \times 10^{-3}$ mm$^2$/s and diffusion-prepared images with severe bulk motion-induced artifacts.

Conclusions
The LV trADC values derived with M1M2 motion compensation diffusion preparation were consistent with previously reported values ranging from 0.8 to $2.4 \times 10^{-3}$ mm$^2$/s [4-6]. The uncompensated diffusion preparation measurements yielded LV trADC values that were much greater suggesting motion corruption. We developed a novel free-breathing bulk motion compensated diffusion-prepared 3D segmented bSSFP technique able to perform in-vivo cardiac diffusion-weighted MRI on a clinical MR scanner.

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Authors’ details
1Biomedical Imaging Research Institute, Cedars-Sinai Medical Center, Los Angeles, California, USA. 2Bioengineering, University of California Los Angeles, Los Angeles, California, USA. 3Radiology, Anzhen, Beijing, China.

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