In vivo Cardiac Diffusion MRI: Second Order Motion Compensated, Diffusion-prepared Balanced Steady State Free Precession (SOMOCO Diffu-prep bSSFP) with prospective navigator-based free breathing

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Introduction: Cardiac diffusion MRI (CDMRI) has the potential to identify acute myocardial ischemia and assess the chronic change of myofiber orientation after a myocardial infarction [1, 2]. Cardiac motion and SNR limitations have been the primary challenges for the application of the technique *in vivo*. A few previous *in vivo* studies have demonstrated the feasibility of CDMRI in humans using diffusion-weighted (DW) EPI. However, these approaches suffer from inherently poor SNR efficiency in the case of STEAM DW encoding [3] or require the use of a reduced field-of-view (FOV) [4]. In addition, they employ a first order motion compensation (MOCO) to account for cardiac motion, while limiting diffusion encoding duration to less than 30 ms to avoid non-constant velocity motion. This severely hinders the ability to achieve an acceptable b-value for CDMRI with clinical hardware limitations. We propose a novel application of diffusion-prepared balanced steady-state free precession (Diffu-prep bSSFP) [5] to include second order MOCO (SOMOCO). This not only allows for sufficiently high b-values, but also takes advantage of the higher SNR efficiency and image quality of bSSFP while ensuring a large FOV.

Materials and Methods: *In vivo* volunteer experiments were performed at 1.5T (MAGNETOM Avanto, Siemens) with SOMOCO Diffu-prep bSSFP (TR/TE=233.2/1.3 ms, FOV=256x256 mm^2, 128x128 matrix, 8 mm short axis slice, δ_1=9.9 ms, G_{diff}=40-56.6 mT/m, TE_{prep} = 60-90 ms, b=0, 200-323 s^1mm^{-2}, timing diagram shown in Fig. 1). Healthy volunteers (n=11) were imaged during the quiescent cardiac phase of diastole. Diffusion encoding was prescribed along readout and/or phase encoding direction(s) for all experiments and multi-shot readout was used to avoid blurring from cardiac motion. ADC maps were calculated offline assuming a monoexponential fit in Matlab. Manual segmentation of the left ventricle (LV) was used to calculate the mean and standard deviation of the ADC values for each volunteer.

Results: The mean ADC values of the LV myocardium for the 11 volunteers were 2.21 ± 0.45 x 10^3 mm^2s^{-1}. Fig. 2 shows a typical b=0 s^1mm^{-2} (Fig. 2a), b = 200 s^1mm^{-2} (Fig. 2b), and accompanying ADC map (Fig. 2c). In the case of acquiring outside of the quiescent phase (mid systole, Fig. 2d), SOMOCO was able to yield appreciable signal (Fig. 2e) while uncompensated prep resulted in complete signal loss of the myocardium (Fig. 2f). Notice the full FOV and excellent image quality attributed to the bSSFP readout chosen for the diffusion preparation.

Conclusion: We have shown the feasibility of using diffusion-prepared acquisitions to derive in-vivo ADC maps of human hearts by employing SOMOCO Diffu-prep bSSFP. ADC values acquired from the 11 volunteers are consistent with prior *in vivo* human cardiac diffusion studies [1,3,4]. The unique use of a multi-shot bSSFP readout could potentially yield 3D undistorted whole-heart DW images, which can better characterize myofiber architecture derived from current EPI based methods.

[1] Wu, et al. Circ 114:10 (2006). [2] Hsu, et al. Am J Heart Physio 275:697 (1998). [3] Dou, et al. MRM 48:105 (2002). [4] Gamper, et al. MRM 57:331. (2007). [5] Jeong, et al. MRM 50:821 (2003).

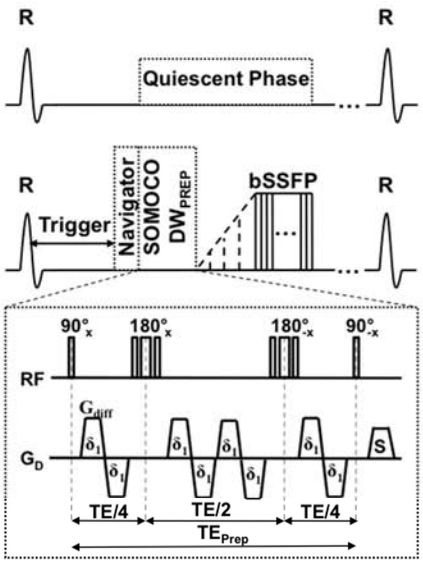

Fig. 1 Timing Sequence Diagram

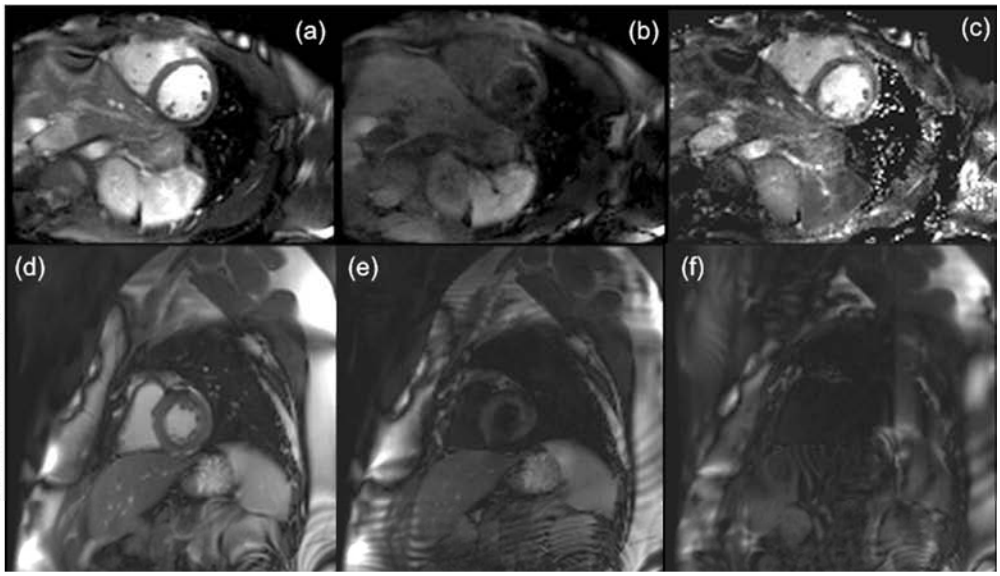

Fig. 2 (a) b=0 s^1mm^{-2}, (b) b = 350 s^1mm^{-2}, (c) ADC map. Case of acquiring during mid systole (d) b=0 s^1mm^{-2}, b = 200 s^1mm^{-2} (e) SOMOCO prep (f) uncompensated prep