In-Vivo High Resolution Diffusion Tensor Imaging of the Human Heart at 3T: Fat Suppression in the Presence of B0 field Inhomogeneities

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Background: Diffusion tensor studies are highly sensitive to bulk motion, severely restricting their use in moving organs such as the heart. However, in recent work diffusion acquisition schemes that employ stimulated echoes (STEAM) [1,2] have been used to allow diffusion gradient lobes to be applied at the same point in the cardiac cycle [3 - 5]. Such acquisition schemes have an inherently low SNR due to the low signal intensity of the stimulated echo pathway. Imaging at high field strengths helps to improve SNR but also increases the problems associated with magnetic susceptibility related off-resonance field effects. Higher order localized image based shimming can partially compensate for the increased field inhomogeneity but, at the same time, compromises the effectiveness of fat saturation techniques such as SPIR [6] across the entire field-of-view. To address this limitation we present a dual navigated STEAM sequence [3] with Slice Selective Gradient Reversal (SSGR) [6] applied to the second and third RF pulses. In-vivo data of the human heart, acquired at 3T, are presented.

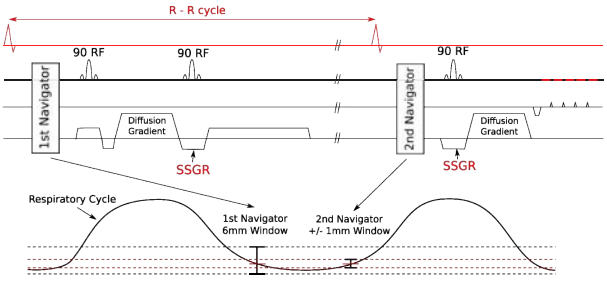

Figure 1 : Simplified version of the stimulated echo diffusion acquisition sequence (readout gradients are not shown). Slice selective gradient reversal is applied to the gradients of the second and third RF pulses to shift fat signal to outside of the imaging slice.

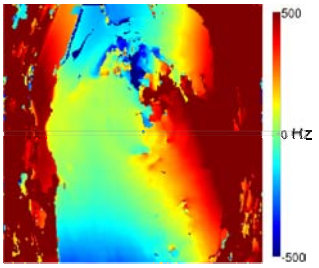

Figure 2 : Post shim ΔB_0 map. Large deviations in regions away from the volume of the heart can be seen.

Methods: Scanning was carried out on a 3T Philips Achieva system (Philips Healthcare, Best, The Netherlands) with a 32 channel receive coil. Images were acquired using a cardiac-triggered and respiratory navigated STEAM acquisition with a single shot EPI readout module (**Figure 1**), at 2mm in-plane resolution and with a slice thickness of 6mm. Fat suppression was assessed by carrying out three repeat DTI acquisitions, one without fat suppression, one with SPIR and one with SSGR. The minimum achievable TE was used for all acquisitions. For the example data set shown in **Figures 3-5** the minimum TE was 13 ms for the non-SSGR scans and 17 ms for the SSGR scan (due to the lower RF pulse bandwidth that is required). Six diffusion directions were acquired [7] with a b-value of 500s/mm^2, and an NSA of 6. An image based shimming technique was employed to calculate 2nd order shims (optimised over the volume of the heart). Readout duration was 20 ms using 2x SENSE and 66% partial Fourier. Respiratory gating was carried out using a 1D pencil beam navigator placed at the right hemi-diaphragm. The navigator was performed in each R-R cycle using gating windows of 6 mm and 2mm for the STEAM encoding and decoding parts, respectively. The 2mm gate was applied relative to the respiratory position as detected by the navigator of the encoding part thereby improving gating efficiency relative to implementation described in previous work [3].

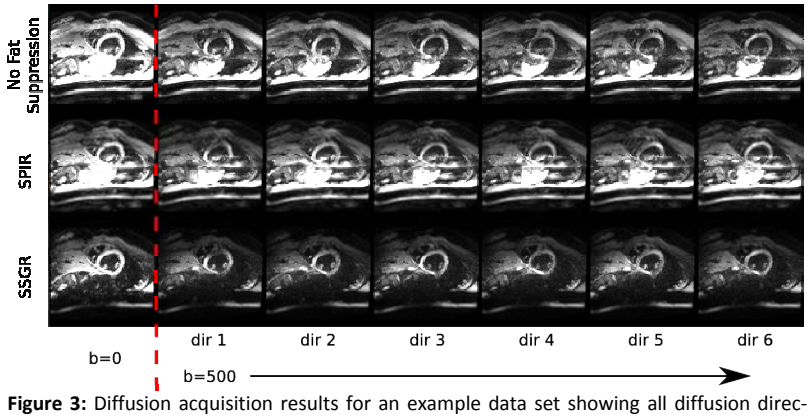

Figure 3: Diffusion acquisition results for an example data set showing all diffusion directions. Results are shown for data acquired without fat suppression (Top Row), whilst employing SPIR fat suppression (Middle Row) and with Slice Selective Gradient Reversal (Bottom Row).

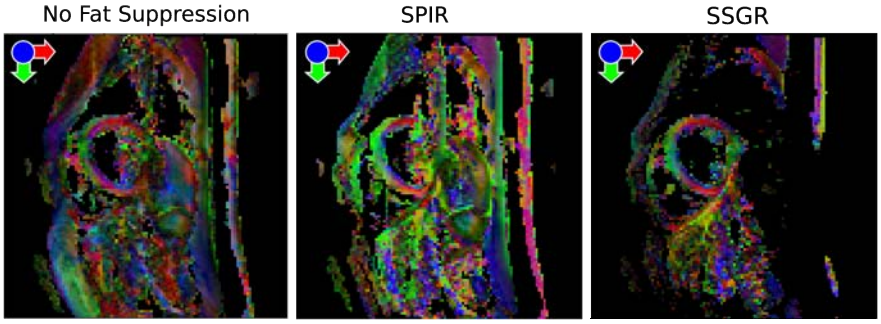

Figure 4: FA maps, colour coded to show the direction of the principal eigenvector of the tensors.

Results: Navigator gating efficiency was ~30%, resulting in scan times of ~5 minutes per slice. Second order shimming proved successful in reducing ΔB_0 inhomogeneities within the heart but also tended to create large field offsets outside of it (**Figure 2**). The effects of fat shift artefacts w/o fat suppression are demonstrated in **Figures 3** and **4** with large artefacts present across the left ventricle. When using SPIR significant artefacts remain. In contrast, SSGR provides robust fat suppression and Fractional Anisotropy maps show circumferentially oriented muscle fibres in both the right and left ventricles (**Figure 3** and **4**) permitting successful reconstruction of tensors (**Figure 5**).

Discussion: We have demonstrated a technique that allows robust fat suppression using SSGR for in-vivo cardiac DTI at 3T, in volunteers where SPIR fat suppression failed. The combination of SSGR with advanced respiratory navigation enabled high-quality reconstruction of tensors in both the right and left ventricles.

References: [1] Tseng et al. MRM 1999. [2] Reese al. MRM, 1995 [2] Stoeck et al. ISMRM, 2012. [3] Nielles-Vallespin et al. MRM, 2012. [4] Toussaint et al. ISMRM 2012 [5] Kaldoudi et al. MRM 1993. [5] [SSGR] Park et al., MRM, 4, 2005 [6] Jones et al. MRM, 1999. **Acknowledgements:** This work is supported by UK EPSRC.

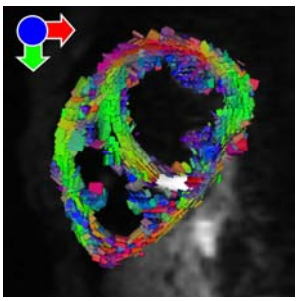

Figure 5: Diffusion tensors from SSGR data.