Correction of Off-resonance Distortions in In-vivo Cardiac Diffusion Tensor Imaging

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Introduction: State-of-the-art diffusion acquisition schemes employing stimulated echo modes (STEAM)[1-4] now allow in-vivo diffusion tensor imaging of the beating heart. Imaging at high field strength helps to alleviate the inherently low SNR of these sequences but also leads to major difficulties associated with off-resonance field effects, such as geometric distortion and signal pileup/attenuation. This is exacerbated by the fact that these pulse sequences almost invariably use single shot EPI readout modules that are extremely sensitive to such field inhomogeneities. Consequently, off-resonance effects are a major obstacle on the road to achieving robust in-vivo cardiac DTI in a clinical setting. Most studies to date have attempted to address this issue by employing reduced FOV imaging strategies and/or parallel imaging in an attempt to minimise the readout duration[1,2,5]. However, these techniques further reduce the SNR of images that are already at the lower bounds of useable SNR, due to the stimulated echo signal pathway and diffusion weighting. In this work we demonstrate the feasibility of performing off-resonance correction as part of the reconstruction process on data acquired both with and without parallel imaging acceleration and show that in-vivo cardiac diffusion tensors can indeed be reconstructed after such correction even in regions of significant geometric distortion.

Methods: Scanning was carried out on a 3T Philips Achieva clinical system (Philips Healthcare, Best, The Netherlands) equipped with a 32 channel receive coil array and dual channel transmit coil. Two data-sets were acquired using a STEAM acquisition with a single shot EPI readout module[2,3], at 2.2mm in-plane resolution and with a slice thickness of 8mm. Thirty diffusion directions were sampled with a b-value of 350s/mm^2. A dual echo time technique was used in a separate scan to generate a ΔB0 map for use in the off-resonance corrected reconstruction pipeline. All data were ECG triggered and acquired at end-diastole. In post-processing, tensors were computed using a non-linear least squares method on the Stejskal-Tanner system of equations from diffusion weighted images. All data were reconstructed using a conjugate gradient iterative SENSE reconstruction technique[6]. For the uncorrected pipeline, forward (**FT**) and backward (**iFT**) encoding functions, based around the Fast Fourier Transform with the addition of coil sensitivity and signal sampling terms, were used for reconstruction. In the distortion corrected pipeline, the forward and backward encoding functions (**E** and **Eh**) were computed directly using an implementation of the discrete Fourier Transform, with phase terms describing both the k-space trajectory and the phase accumulation due to the presence of magnetic field inhomogeneities during signal acquisition.

Results: The raw diffusion data along with simplified reconstruction pipelines are presented in **Figure 1.** A comparison of the morphology, from an undistorted anatomical acquisition (without an EPI readout module), to that of the single shot EPI data from the standard reconstruction pipeline highlights the presence of severe geometric distortions and signal pileup in the free wall of the left ventricle. The reason for this can be clearly seen in the ΔB0 map in **Figure 1**, in this region there is a significant field inhomogeneity due to the presence of a magnetic susceptibility gradient at the interface between the myocardium and lung tissue and due to the presence of the posterior vein[7]. This varies from around 100-150Hz in the region. At a bandwidth per pixel of ~30Hz in the phase encoding direction, this equates to a shift of up to 5 pixels. Applying the off-resonance corrected reconstruction to the same data with the addition of ΔB0 information from a separate scan almost entirely removes this effect whilst restoring diffusion tensor information. In **Figure 2** data from an acquisition with SENSE acceleration (R = 1.5) is also shown, again good distortion correction is achieved (red circle).

Discussion: We have demonstrated the feasibility of acquiring fully sampled single-shot in-vivo cardiac DTI data at 3T, in order to maximise the amount of SNR that is available to reconstruct diffusion tensor data, by employing off-resonance correction as part of the reconstruction process. We have demonstrated that such correction can be used to accurately reconstruct the correct geometry in areas of severe geometric distortion and signal pileup, whilst still allowing diffusion tensors to be reconstructed.

References: [1] Harmer et al. EHJ, 2013 [2] Stoeck et al. ISMRM, 2012 [3] Edelman et al. MRM, 1994 [4] Reese et al. MRM, 1995 [5] Nielles-Vallespin et al. MRM, 2012 [6] Pruessmann et al. MRM, 2001. [7] Reeder et al. MRM, 1998. **Acknowledgements:** Work supported by UK EPSRC.

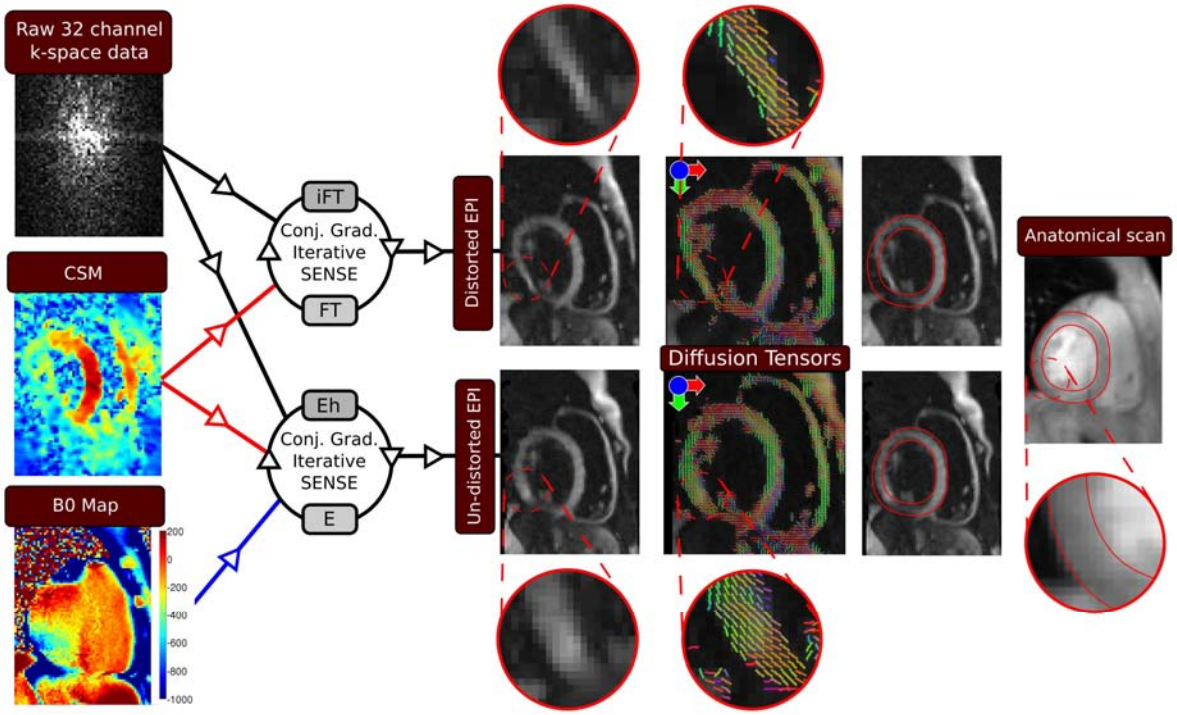

Figure 1: *Simplified reconstruction pipeline for off resonance correction of single-shot EPI stimulated echo in-vivo cardiac DTI data. In the uncorrected pipeline, the raw k-space data is fed, along with coil sensitivity maps (CSM) into a conjugate gradient based iterative SENSE module. Large distortions are evident in the free wall of the left ventricle in the uncorrected single shot EPI data. In the off-resonance corrected pipeline ΔB0 information is used to successfully correct these distortions. The principal eigenvector of the diffusion tensors are*

Figure 2: *Distorted and corrected images from a dataset acquired with SENSE acceleration (R=1.5).*