

Feasibility of whole heart DTI and IVIM with a 15 minute acquisition protocol

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Introduction: In recent years in vivo cardiac DTI using stimulated echo's (STE) has matured into a reproducible technique [1]. However the STE approach requires two heartbeats and intrinsically has a 50% lower SNR compared to spin-echo (SE). Although the STE method allows for short TE (23ms [1]) it also suffers from T1 signal decay and typically 8 signal averages (16 heartbeats) are needed for a single slice acquisition. In this study we aimed to develop a SE-based cardiac diffusion MRI protocol that allows for whole heart DTI as well as intra-voxel coherent motion (IVIM) for perfusion assessment.

Methods: Images were acquired with cardiac triggering (200ms) and free breathing on a 3T scanner (Philips, Achieva) using a 16-channel coil (Torso XL). DWI was performed using a SE sequence with bipolar diffusion weighting gradients [2] and additional flow compensation (Figure 1A). A reduced FOV was obtained using outer volume suppression [3]. The diffusion weighting gradients were applied in 3 orthogonal directions with for b-values of 30, 60, 90, 120s/mm² and in 12 directions for a b-value of 300s/mm². Additionally 4 non-weighted images were acquired resulting in 28 volumes. Every volume was acquired twice resulting in a total acquisition time of 15min for a heart rate of 60bpm. Further parameters were; FOV:280x150mm², voxel size: 6x2.5x2.5 mm³, slices: 16, BW-EPI: 42Hz TR: 8 heartbeats, TE: 55ms. First data was registered to correct for heart- and breathing motion using a 2D non-rigid method followed by Rician noise suppression. Finally data was fitted to

$$S(b,g)=S_0((1-f)\cdot\exp(-b\cdot gDgT)+f\cdot\exp(-b\cdot gDgT\cdot D^*))$$

using a constrained non-linear least squares method. Fiber tractography was performed the vIST/e toolbox with a step size of 0.2 voxel. Stopping criteria were 0.1<FA<0.6 and an angle change of 20° per step.

Results: The corrected DWI images for b=300 s/mm² are shown in Figure 1B. Figure 2A to D show parameter maps for MD, FA, f and D* resulting from the combined IVIM and tensor fit. The average values for the whole heart were $1.67\pm 0.49 \cdot 10^{-3}$ mm²/s, 0.46 ± 0.20 , 0.27 ± 0.16 , $52.68\pm 52.61 \cdot 10^{-3}$ mm²/s respectively. The cardiac helical fiber organization could be reproduced by fiber tractography as shown in figure 2E to G where the fiber tracts are color coded for the helix angle.

Conclusion: In this study we have shown that it is feasible to acquire whole heart DTI and IVIM data within a 15 min protocol in free breathing. Using this approach we were able to quantify the diffusion and perfusion and visualize the fiber architecture.

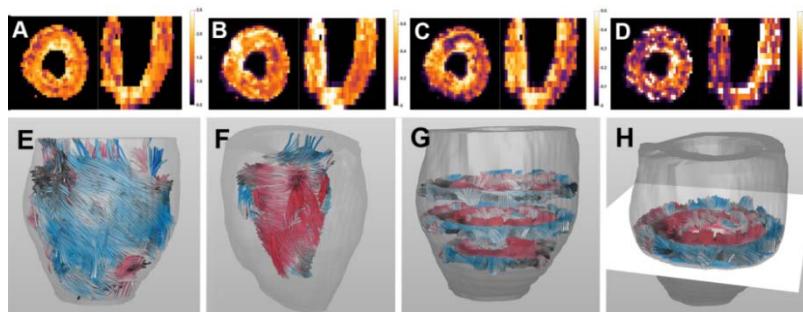


Figure 2: A-D) Parameter maps based on the IVIM fit (A: MD in 10^{-3} mm²/s, B: FA, C: fraction, D: D* in 10^{-3} mm²/s). E-F) whole heart fiber tractography based on the IVIM tensor fit color coded for helix angle. (E: whole heart, F: Inside of the myocardial wall with papillary muscle, G-H: local fiber orientation for different cross sections)

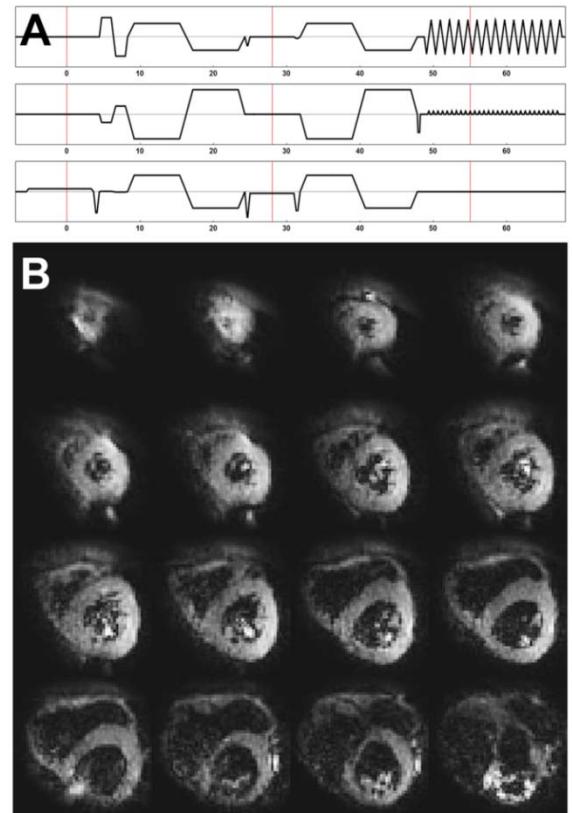


Figure 1: A) Diffusion-weighted SE sequence with bipolar diffusion encoding and flow compensation gradients directly after the 90 degree slice selection. B) The acquired single shot diffusion weighted data for b= 300 s/mm², with a voxel size of 6 x 2.5 x 2.5 mm and TE =55ms

References: [1] S Nielles-Vallespin et al. MRM. 2013, 70:454–465 [2] U Gamper MRM 2007, 57:331–337. [3] BJ Wilm et al NMR Biomed. 2009; 22: 174–181