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

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Background

In recent years in vivo cardiac DTI using stimulated echo's (STE) has matured into a reproducible technique. 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 (23 ms) 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 (200 ms) 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 and additional flow compensation (Figure 1A). A reduced FOV was obtained using outer volume suppression. The diffusion weighting gradients were applied in 3 orthogonal directions with for b-values of 30, 60, 90, 120 s/mm^2 and in 12 directions for a b-value of 300 s/mm^2. Additionally 4 non-weighted images were acquired resulting in 28 volumes. Every volumes was acquired twice resulting in a total acquisition time of 15 min for a heart rate of 60 bpm. Further parameters were; FOV:280 × 150 mm^2, voxel size: 6 × 2.5 × 2.5 mm^3, slices: 16, BW-EPI: 42 Hz TR: 8 heartbeats, TE: 55 ms. 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: $S(b, g) = S0((1\text{-}fr)\ \exp(-b\ g\ \mathbf{D}\ g^T) + fr\ \exp(-b\ g\ \mathbf{D}\ g^T\ D^*))$ 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/mm^2 are shown in Figure 1B. Figure 2A to 2D 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 ± 0.49*10^{-3} mm^2/s, 0.46 ± 0.20, 0.27 ± 0.16, 52.68 ± 52.61*10^{-3} mm^2/s respectively. The cardiac helical fiber organization could be reproduced by fiber tractography as shown in Figure 2E to 2G where the fiber tracts are color coded for the helix angle.

Conclusions

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.

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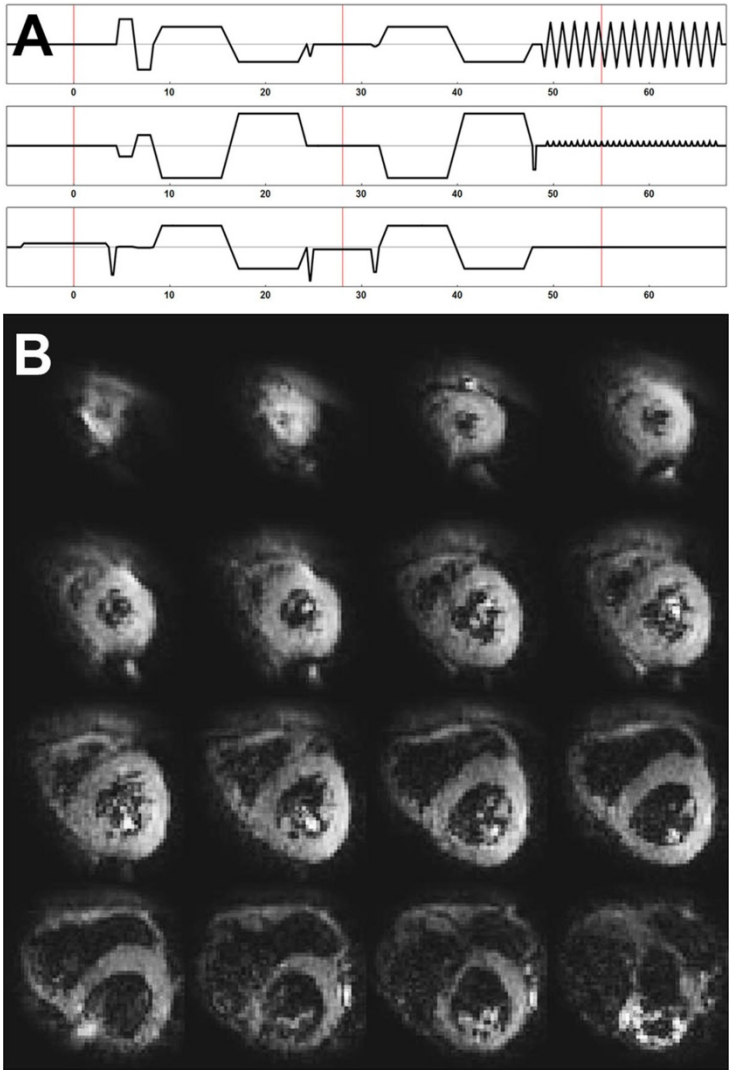

Figure 1 A) Diffusion-weighted SE sequence with bipolar diffusion encoding and flow compensation gradients directly after the 90 degree slice selection. B) The acquired single shot diffusion weighted data for b = 300 s/mm^2, with a voxel size of 6 × 2.5 × 2.5 mm^3 and TE = 55 ms

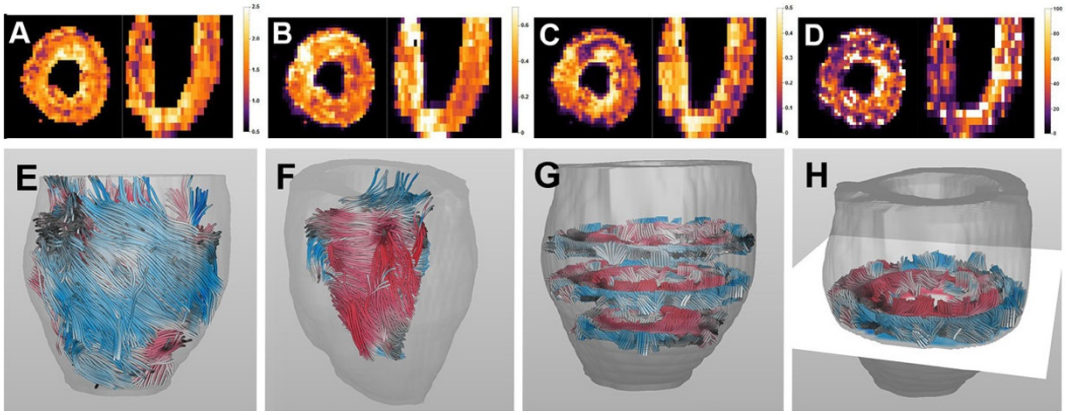

Figure 2 A-D) Parameter maps based on the IVIM fit (A: MD in 10-3 mm^2/s, B: FA, C: fraction, D: D* in in 10-3 mm^2/s). E-F) whole heart fiber tractography based on the IVIM tensor fit color coded for helix angle. (E: whole heart, F: Inside of the myocardial wall with papillary muscle, G-H: local fiber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

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