Joint reconstruction of quantitative T2 and apparent diffusion coefficient (ADC) maps in the heart

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Background
Myocardial tissue characterization with T2-weighted imaging is an established technique for evaluating the presence of myocardial edema or iron overload (Kellman, P. MRM 2007, Anderson, LJ. EHJ 2001). More recently, both T2-mapping and apparent diffusion coefficient (ADC) mapping have emerged as quantitative techniques for characterizing edema (or iron overload) and water mobility. The purpose of this work was to develop a framework for the simultaneous recovery of both T2 and ADC from a single breath-hold acquisition.

Methods
Spin echo (SE) diffusion weighted imaging (DWI) signals are principally governed by the tissue’s apparent diffusion coefficient (ADC=D) and T2 relaxation, as well as the sequence’s diffusion encoding b-value (b) and echo time (TE): S(b,TE) = S0e-bDe-TE/T2. We propose that acquisition of several signals with varying TEs and b-values permits joint reconstruction of both ADC and T2 maps.

Bloch equation simulations were used to generate signals for a broad range of T2 (20-70ms) and ADC (0.1-2.4×10^-3 mm²/s) using 10 TEs (17-100 ms) and b=500 s/mm² (TE=60-68ms) along 3 directions. Complex Gaussian noise was added to each signal such that the signal to noise ratio (SNR) of the minimum TE, b=0 signal matched that of acquired data (SNR = 38). Reconstructions were performed using linear least-squares on a subset of the simulated data (TE=17,20,30,50,70,100ms) to reflect a feasible in vivo acquisition (scan time:18s). Mapping accuracy and precision were determined by the bias and standard deviation (SD) of T2 and ADC compared to programmed values.

Images were acquired on a 3.0 T Siemens Skyra system in an ex vivo infarcted porcine heart using single-shot SE EPI with TEs and b-values to match simulated parameters. T2 and ADC maps were jointly reconstructed using linear least-squares from 6 TEs plus 3 DWI sets and compared to: 1) Best-Available T2-maps from all 10 TEs; 2) Best-Available ADC maps from DWI (3 directions, 6 averages); 3) Independent T2 maps from 6 TEs; and 4) Independent ADC maps from 3 DWI averages.

Results
Joint reconstruction of simulated data recovered T2 and ADC values with bias<1% and SD<10% for a broad range of tissues and even lower for healthy and infarcted myocardium (Table 1).

Reconstructed ADC and T2 maps from the ex vivo acquisition are shown in Figure 1. Joint estimation maps were closer to the Best-Available T2 or ADC maps than the Independent T2 or ADC maps alone (Joint Estimation Maps: T2-bias=-0.5 %, ADC-bias=-4.8%; Independent Maps: T2-bias=-4.1%, ADC-bias=-14.1%).

Conclusions
Joint acquisition and estimation of T2 and ADC maps is feasible in a breath hold and improves quantitative accuracy and precision compared to independent T2 or ADC mapping. DWI acquisitions typically require multiple averages to improve SNR. Here, varying TE takes the place of signal averaging and permits the reconstruction of a perfectly registered T2 map.

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Table 1 Simulation results

|                | T2 Bias | T2 SD | ADC Bias | ADC SD |
|----------------|---------|-------|----------|--------|
| Healthy (T2=56ms, ADC=1.69x10^{-3}mm^2/s) | 0.3 %   | 4.5 % | -0.3 %   | 7.0 %  |
| Infarction (T2=69ms, ADC=2.4x10^{-3}mm^2/s) | 0.2 %   | 4.6 % | 0.2 %    | 5.6 %  |

Figure 1 Ex vivo ADC and T2 maps from 10 TE s and 6 DWI averages, respectively (left), 6 TE s and 3 DWI averages (right) and Joint reconstruction from 6 TE s and 3 DWI sets (center). Joint estimation maps were closer to the Best-Available T2 or ADC maps than the Independent T2 or ADC maps alone and came with no increase in scan time.

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