Joint Reconstruction of Quantitative T_2 and ADC Maps In The Brain Using Spin Echo Diffusion Weighted Imaging

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PURPOSE: To demonstrate the feasibility of a novel technique for joint acquisition and reconstruction of T_2 and ADC maps in the brain.

INTRODUCTION: Quantitative MRI is an increasingly useful tool for a variety of clinical applications. Specifically, T_2 and Apparent Diffusion Coefficient (ADC) mapping are both used to evaluate microstructural environments and can provide insight into the presence and extent of several neurologic pathologies. By exploiting the ADC and T_2 dependence of spin-echo diffusion weighted imaging (SE-DWI), we can recover both maps from a DWI acquisition at no cost in scan time. These maps are perfectly co-registered and therefore well suited for applications such as surgical planning that requiring high spatial correlation.

THEORY: SE-DWI signals are governed by the tissue's ADC (*D*) and T_2 relaxation time, as well as the sequence's diffusion encoding b-value (*b*) and echo time (TE) according to: $S(b,TE) = S_0 e^{-bD} e^{-TE/T2}$. We propose that acquisition of several signals with varying TEs and b-values permits joint reconstruction of both ADC and T_2 maps (Figure 1).

$$\begin{bmatrix} ln(S_0) \\ \frac{1}{T_2} \\ D \end{bmatrix} = \begin{bmatrix} 1 & -TE_1 & -b_1 \\ 1 & -TE_2 & -b_2 \\ & \vdots & \\ 1 & -TE_N & -b_N \end{bmatrix}^{-1} \begin{bmatrix} ln(S_1) \\ ln(S_2) \\ \vdots \\ ln(S_N) \end{bmatrix}$$

Figure 1. Matrix formalism of joint T_2-ADC recovery from N signals weighted by T_2 and diffusion (*D*).

METHODS: *Image Acquisition* — Single-shot SE-DWI EPI images were acquired using a 3.0 T scanner (Siemens Prisma) and a polyethylene glycol (PEG) and gadolinium phantom[1] which contained a range of T_2 and ADC values known nominally from chemical composition using 1.0x1.0x5.0mm resolution, GRAPPA factor 2, 5/8 partial fourier, bandwidth=1000 Hz/Pixel, TR=3800ms. The acquisitions spanned a range of ten TEs (TE=35-100ms) each acquired four times and also included DWI (b=1000 s/mm^2) along three directions at four TEs (TE=60,65,70,75ms) each acquired ten times. Whole volume brain images were acquired using the same protocol in healthy volunteers (N=5) subsequent to IRB approved consent.

Image Reconstruction – Three subsets of the acquired images with matched acquisition durations were reconstructed. ***Jointly reconstructed T_2 and ADC maps*** were generated using weighted linear least-squares from 8 TEs plus DWI spanning 4 TEs (2 averages each, scan time: 2.5min) and compared to ***reference T_2 maps*** from all 10 TEs (4 averages, scan time: 2.5min) and ***reference ADC maps*** from DWI (TE=60ms, 10 averages, scan time: 2.5min). The bias±95% confidence interval (CI) of joint T_2 and ADC reconstructions were calculated by voxel-wise subtraction from the reference maps. T_2 and ADC estimates in two ROIs in the PEG phantom (PEG_1 and PEG_2) and in white-matter (WM) and grey-matter (GM) ROIs were compared using a paired t-test.

RESULTS: T_2 and ADC values for the joint and reference reconstructions were both in agreement with the nominal T_2 and ADC values in the PEG phantom (Figure 2).

	Reference T_2	Joint T_2	Reference ADC	Joint ADC
	[ms]	[ms]	[x10-3 mm2/s]	[x10-3 mm2/s]
PEG_1	42.1 ± 7	41.9 ± 9†	0.5 ± 0.3	0.5 ± 0.3†
PEG_2	194.8 ± 15	195.1 ± 22†	2.1 ± 0.05	2.1 ± 0.1†
WM	72.6 ± 2	73.7 ± 2‡	0.68 ± 0.02	0.66 ± 0.03‡
GM	61.0 ± 4	61.4 ± 3‡	0.79 ± 0.1	0.81 ± 0.1‡

Figure 2. T_2 and ADC measurements from joint and reference scans in the PEG phantom (median±intra-ROI standard deviation) within two ROIs. For PEG_1 the nominal T_2=46±2ms and ADC=0.53±0.01mm^2/s. For PEG_2 the nominal T_2=180±8ms and ADC=2.2±0.04mm^2/s. WM and GM ROIs across the five healthy subjects (median±inter-subject standard deviation) are also compared for joint and reference scans. No significant differences were found for joint versus reference reconstruction (†p>0.1 and ‡p>0.6)

Voxel-wise comparison of the pooled joint T_2 and ADC data to the reference T_2 and ADC data showed that joint reconstruction did not introduce substantial bias: T_2-bias=0.5±37ms and ADC-bias=0.01±0.8 x10^{-3}mm^2/s. There was no significant difference between the median T_2 or ADC values reported in WM or GM ROIs (Figure 2) by the joint and reference reconstructions (p>0.6). Jointly reconstructed ADC and T_2 maps from an *in vivo* acquisition are shown alongside reference ADC and T_2 maps in Figure 3 and demonstrate excellent qualitative agreement between the methods.

DISCUSSION: Due to inherently low SNR, DWI acquisition usually entails multiple repetitions and averaging. In the proposed method, the TE is varied with each repetition in place of averaging. When coupled with the acquisition of non-DWI short TE images, this permits the reconstruction of a quantitative T_2 map in addition to the ADC map with no increase in scan time compared to independently acquiring each. These preliminary results show that there is no significant difference between the joint T_2 and ADC maps. Note that the availability of ultra-high gradient systems (G_{max}=80mT/m) accommodates shorter TEs and better enables accurate T2 estimates with TEs that are less than the nominal T2. Lastly, while no significant bias was introduced, the joint T_2 and ADC maps are noisier than the reference maps. SNR will likely improve by optimizing the choice of T_2 and ADC weighting.

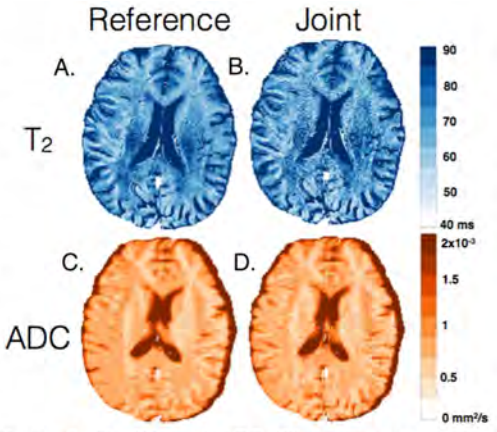

Figure 3. T_2 (A) and ADC (C) brain maps from reference protocols compared to jointly reconstructed T_2 (B) and ADC (D) maps acquire in the same time as (A) or (B).

CONCLUSION: Joint acquisition and estimation of T_2 and ADC maps is feasible in the brain and introduces no loss in accuracy when compared to independent mapping protocols that require twice the scan time.

REFERENCES: 1. Gaddis, S. et al. MRM 2014; 72:459–463