Microscopic ADT Determination with Multiple Echo Manipulation to Improve Efficiency and Accuracy

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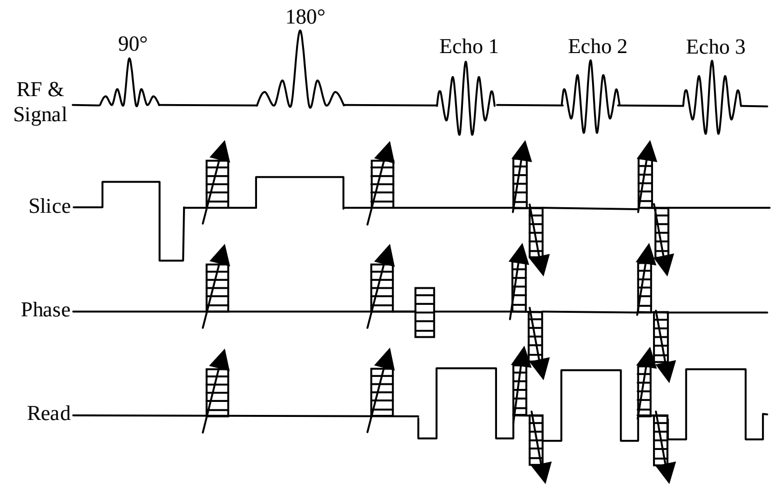
Introduction

Apparent diffusion tensor (ADT) mapping requires the acquisition of at least seven images with diffusion weighting in different directions. However, accurate calculation of various anisotropy indices (1) often necessitates a greater number of images, a constraint that can result in long data acquisition times. In high-field MR microscopy, as opposed to human applications, rapid imaging techniques such as echo-planar imaging (EPI) cannot be used to alleviate the problem due to large magnetic susceptibility effects. Multiple spin-echo manipulation has previously been suggested as a method to reduce imaging time for microscopy (2). Here, we propose an alternative imaging sequence which consists of a diffusion-weighted spin echo, followed by a train of gradient echoes with additional diffusion weighting provided by bipolar gradient pulses (Figure 1). Each echo contributes to different images, which are used to reconstruct an ADT and a T_2^* map. We demonstrate the feasibility of this method on excised and fixed rat spinal cords.

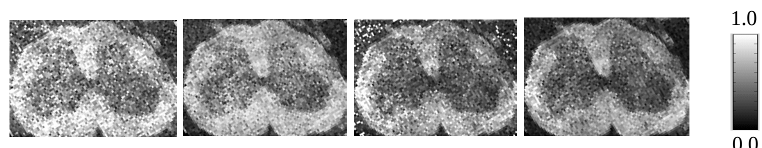


Methods

The imaging sequence was implemented on a Bruker 750 MHz spectrometer (Bruker Biospin, Ettlingen, Germany), equipped with imaging gradients (1 T/m maximum gradient strength), and a home-built 11 mm TEMRF resonator. The sequence was tested on thoracic spinal cords excised from adult DA rats, and fixed with 4% paraformaldehyde. Prior to imaging, the cords were immersed in phosphate buffered saline (PBS) and placed in a 5 mm NMR tube. Imaging parameters include TR 1.1 s, TE 13.7, 23.1 and 32.9 ms, 400 µm slice thickness, 5 mm x 5 mm FOV, 128 x 128 data matrix (39 µm in plane resolution), and 4 signal averages. Images were reconstructed using Matlab (The Mathworks, Natick, MA, USA). The diffusion and T_2^* signal decay was modeled as follows:

$$I = I_0 \exp\left[-\sum_{i,j,k} b_{ij,k} D_{ij} - (TE - TE_1)/T_2^* \right] \qquad b_{ij,k} = \sum_k \gamma^2 \iint G_{i,k}\, dt' \int G_{j,k}\, dt'\, dt$$

where k represents the echo number, and i and j the various diffusion gradient directions. The diffusion tensor, trace, A_σ, and fractional anisotropy (FA) maps were obtained from just the spin echo (first echo in this sequence) images using 7 or 13 images/diffusion encoding directions, and from 21 or 39 images (7 x 3 or 13 x 3) using the new imaging sequence. Imaging times were 1.1 hrs to obtain 7 or 21 images, and 2.0 hrs for 13 or 39 images..



(a) (b) (c) (d)

Fig 2: FA maps constructed from (a) 7 spin echo images (b) 13 spin echo images, (c) 21 images from new sequence (d) 39 images from new sequence

Results

The calculated FA maps are shown in Figure 2. The maps in (a) and (b) are reconstructed from 7 and 13 spin echo images, respectively, while those in (c) and (d) are obtained from 21 and 39 spin-echo and multiple gradient echo images. Trace, A_σ, and T_2^* maps (the latter from the multiple echo sequence only) were also obtained. Quantitative comparisons were performed, and FA values from identical ROIs are tabulated below (from a second experiment).

Discussion

As can be seen from Figure 2, the maps reconstructed from 7 and 13 spin-echo images are noisier than those obtained from 21 and 39 images from the multiple echo acquisition. This is also illustrated by the progressively smaller error bars for the FA values in the table. Additionally, the FA values in the known isotropic medium (PBS) become smaller and closer to zero when calculated with a larger number of images, as expected from the analysis of (1). The FA values are in close agreement with FA of 0.73 and 0.20 in lateral column white matter and ventral horn gray matter, as calculated from our own previously published data on excised fixed cords, at a different field strength (3). It is worth noting that the error bars and quality of calculated maps are improved with 21 images from the multi-echo acquisition in comparison with the 13 images obtained using the standard acquisition. The results thus represent both improved quality and increased efficiency since the 21 images are obtained from a time-equivalent of 7 spin-echo images, a nearly 50% savings in time compared to the 13 image experiment. There is also additional information provided by a T_2^* map. This method therefore offers significant advantages for ADT microimaging.

	FA from Standard Spin Echo ADT Sequence, ± sd		FA from Multi-echo ADT Sequence, ± sd	
Number of images used	7	13	21	39
Water (PBS), 48 pixel ROI	0.17±0.07	0.15±0.05	0.11±0.04	0.09±0.03
Lateral column white matter, 61 pixel ROI	0.87±0.22	0.85±0.20	0.75±0.17	0.74±0.14
Ventral horn gray matter, 11 pixel ROI	0.42±0.18	0.39±0.17	0.26±0.14	0.27±0.12

References

(1) Pierpaoli and Basser, MRM. 1996;36:893-906
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Acknowledgments

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