Benefits of higher magnetic fields for diffusion tensor imaging (DTI) based on single-shot STEAM MRI sequences: *In vivo* mouse brain studies at 2.35 T and 7 T

S. Boretius[1], J. Wuerfel[2], F. Zipp[2], T. Watanabe[1], J. Frahm[1], T. Michaelis[1]

[1]Biomedizinische NMR Forschungs GmbH, Max-Planck-Institut fuer biophysikalische Chemie, Goettingen, Germany, [2]Institute of Neuroimmunology, Research Center, Charite University Hospital, Berlin, Germany

Introduction

In theory, the NMR signal is expected to scale more than linearly with magnetic field strength [1]. On the other hand, practical MRI applications such as diffusion tensor imaging (DTI) using echo-planar imaging (EPI) are also affected by a marked reduction of T2 and T2* relaxation times, the latter referring to enhanced magnetic field inhomogeneities with corresponding geometric distortions and signal losses. Because of the physical nature of radiofrequency-refocused echoes as opposed to gradient echoes, single-shot STEAM MRI sequences [2-4] are immune to these effects and may exploit the full advantage of the increased longitudinal magnetization and prolonged T1 relaxation times at higher fields. The purpose of this study was to experimentally confirm and quantify putative gains by comparing maps of the fractional anisotropy and main diffusion direction of mouse brain *in vivo* obtained by half Fourier (HF) diffusion-weighted (DW) single-shot STEAM MRI at 2.35 T and 7 T.

Methods

HF DW single-shot STEAM MRI was implemented on a 2.35 T Bruker DBX system with B-GA20 gradients (100 mTm^{-1}) and a 7 T Bruker pharmascan with B-GA12 gradients (300 mTm^{-1}). At 2.35 T the study employed a 100-mm Helmholtz coil for rf excitation in conjunction with a circular surface coil (16 mm inner diameter) for signal reception. At 7 T a quadrature birdcage coil (20 mm inner diameter) was used in transmit-receive mode. Diffusion preparation involved two b-values (10, 1000 s mm^{-2}) in 2×6 different directions with a diffusion time of 15 ms for both systems. The mice were anaesthetized by isoflurane inhalation using artificial ventilation (2.35 T) or spontaneous breathing (7 T).

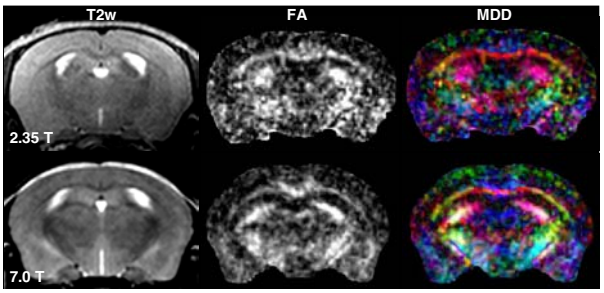

Fig.1: T2-weighted images (T2w) and corresponding maps of the fractional anisotropy (FA) and color coded main diffusion direction (MDD) at 150x150x1000 μm^3 resolution obtained at 2.35 T and 7 T in measuring times of 179 and 23 min, respectively.

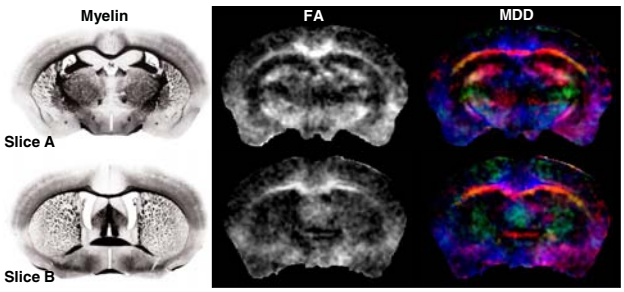

Fig.2: Maps of the fractional anisotropy (FA) and color coded main diffusion direction (MDD) at 117x117x720 μm^3 resolution obtained at 7 T in a measuring time of 176 min.
Left: Corresponding histological sections (www.hms.harvard.edu).

Results and Discussion

Differences in hardware and NMR relaxation times required a number of experimental adjustments for the implementation of HF DW STEAM MRI sequences at 2.35 T and 7 T. For example, the higher gradient strength available at 7 T allowed for shorter diffusion gradients (2.7 ms vs 8.5 ms) and echo times (22.3 ms vs 28.8 ms) partially compensating for the reduced T2 relaxation time. Because of the longer T1 the repetition time had to be increased from 5 to 7.5 s which could be invested in a larger number of sections. When keeping the FWHM of the point spread function constant, the longer T1 and increased bandwidth at 7 T (390 Hz/pixel vs 102 Hz/pixel) allowed for a higher flip angle of the readout pulses (14° vs 11°) which together with the increased longitudinal magnetization resulted in an SNR increase by a factor of about 2.7. As shown in Figure 1 this signal gain can be successfully used to reduce the measurement time for a DTI data set at 150 x 150 x 1000 μm^3 resolution from about 3 h (2.35 T) to 23 min (7 T). Please note that with STEAM MRI no additional distortions were observed at 7 T. Alternatively, when using a measurement time of about 3 h the resolution could be improved to 117 x 117 x 720 μm^3 as demonstrated in Figure 2. As far as quantitative FA values are concerned the various acquisitions at different resolution and field strength revealed similar values in the corpus callosum as well as in the cortex (calculated from 2 ROIs in 5 different sections). The Table summarizes the main results obtained at the two field strengths.

Conclusion

The advantages predicted for DW single-shot STEAM MRI at higher magnetic fields indeed offer substantial practical gains. For a threefold increase in field strength as tested here, the measuring time may be reduced by a factor of 8 or the spatial resolution may be increased by a factor of 2.3 (reduction of voxel size) – still with an even better SNR. Further improvement is expected by using adapted surface coils. With respect to the importance of brain research in genetically modified mice, the achieved resolution and image quality offers a suitable way for the evaluation of neuronal fibers in animal models of neurodegeneration.

References

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Acknowledgment

This study is supported by the Gemeinnützige Hertie Stiftung, Institute of Multiple Sclerosis Research, Göttingen.

Field strength / T	**2.35**	**7.0**	**7.0**
Resolution / μm^3	150x150x1000	150x150x1000	117x117x720
Measurement time / min	179	23	176
SNR (b=10 s mm^{-2})	17±2	19±2	22±2
FA (corpus callosum)	0.49±0.08	0.42±0.06	0.56±0.02
FA (cortex)	0.25±0.02	0.25±0.02	0.23±0.02