High-resolution Diffusion Tensor Imaging (DTI) of the human head at 7T: first results with a 70 mT/m whole body gradient system

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Introduction

High resolution diffusion tensor imaging (DTI) provides a step towards depicting in vivo smaller fiber tracts such as U-fibers between different cortical and subcortical functional areas. Additionally, smaller pathologies might be detected at an earlier stage [1-4]. Ultra-high fields such as 7T will be advantageous as an initially higher signal-to-noise ratio should allow increased resolution. Stronger gradients are required to achieve large diffusion-weighting (b-factors) while maintaining acceptable TE times which is a prerequisite to examine potentially multi-exponential behavior of the diffusion coefficients or to use methods such as q-space imaging. However, ultra high field conditions provide additional problems mainly due to B_1 inhomogeneity with ill-defined flip angles, increased susceptibility artifacts, and shortened T2 values. Thus, a major strategy to reduce EPI- and T2-related distortions as well as signal losses consists in reducing TE. DWI usually prolongs TE as diffusion-weighting gradients (DWG) have to be inserted. We aimed to overcome these problems by using the first available 70 mT/m whole body gradient system for a 7T MR scanner and applying an improved DTI sequence with the option of a single refocusing pulse.

Methods

Measurements were conducted on a 7T whole body system (Siemens, Erlangen Germany) equipped with a whole body gradient system (70 mT/m, 200 T/m/s), and a 24 channel phased array head coil for reception with a CP transmission (Nova Medical, USA).

For diffusion imaging a work-in-progress sequence was used that was improved for ultra-high field imaging (Siemens Medical Solutions USA). Compared to the standard DTI sequence the following improvements were realized: 1) trapezoidal gradients were disabled in favor to pure sinusoidal gradients, 2) RF pulses were more flexible with respect to type, duration, and bandwidth-time product, 3) flexible fat saturation pulse flip angle, 4) alternative diffusion encoding schemes, 5) user-defined diffusion directions, 6) alternating diffusion vector polarities for multiple averages, 7) multiple concatenation for optimized physiological triggering, and 8) automatic TE minimization.

In BOLD imaging at 7T using gradient echo EPI the short T2* of fat allows to dismiss fat saturation [5] while the long T2 of fat in spin echo diffusion EPI requires strong fat saturation. To reduce specific absorption rate (SAR) the fat saturation angle was set to 90°. For excitation and refocusing pre-defined SINC pulses were used with a length of 3072 ms (90°) and 7680 ms (180°) further reducing the fat signal due to incomplete fat refocusing [6]. To reduce SAR further as well as to reduce TE the monopolar diffusion scheme leading to a single refocusing echo was applied. Images were acquired with b=0 s/mm^2 and b=1000 s/mm^2, with 30 diffusion-encoding directions. Other sequence parameters were: flip angle 90°/180°, TR/TE= 5200/52 ms, BW 1700 Hz, 64 slices, matrix 140x140, slice thickness 1.4 mm (gap 10%) leading to isotropic DTI with a resolution of 1.4x1.4x1.4 mm^3. GRAPPA factor of 3 was applied to reduce distortions and TE. Two averages and two alternating diffusion vector polarities were used.

Data were registered externally using a cross-correlation algorithm implemented in MATLAB 2009b. Subsequently registered data were averaged, and further post-processed using FSL [8]. This resulted in maps of the mean apparent diffusion coefficient (ADC), fractional anisotropy (FA) maps, and principal diffusion directions (PDD). Mean ADC values were determined by evaluating 4 ROIs in white matter and CSF.

Results and discussion

DWI exhibited strongly reduced distortions and a good tissue contrast between white and gray matter as compared to former images using the 40mT/m gradients and the non-optimized standard DTI sequence. This improvement was mainly due to the reduced echo time. With stronger gradients, the improved ultra-high field diffusion sequence, and parallel imaging a minimum TE of 52 ms was reached for these measurement parameters. However, the small voxel size required to average several images to reach sufficient and reliable post-processing results. Despite averaging, there remained some signal fluctuations and signal inhomogeneities (especially in the frontal regions near the sinus) as well as regions with very low signals (mainly in the caudal brain parts). In contrast, the parietal, medial, temporal, and occipital brain parts showed good quality that allowed a reliable determination of the diffusion imaging parameters (ADC, FA, and PDD maps). Fig. 1 shows the PDD maps in three orthogonal views. The larger white matter tracts are clearly depicted together with the main diffusion directions. Mean ADC value for white matter is 713 ± 56 μm^2/s and 2554 ± 149 μm^2/s for CSF. These Values are in good agreement with former reports [3]. Fig. 2 depicts an enlarged part of the color-coded diffusion vector maps masked with the FA map overlaid on the T2-weigthed b0 image. Although the single refocusing echo sequence shows a higher sensitivity for eddy currents the shorter TE and resulting higher signal to noise ratio enabling a high resolution outweighs this potential disadvantage.

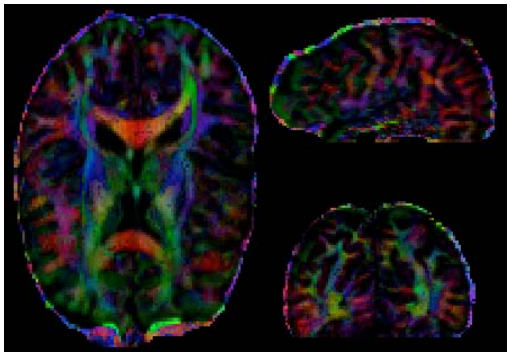

Fig. 1: color-encoded PDD maps

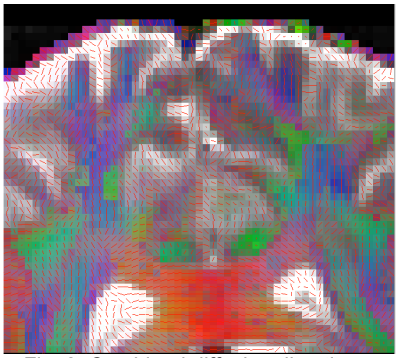

Fig. 2: Combined diffusion directions, FA overlaid on T2-weighted image

Conclusion

Diffusion imaging profits significantly from higher gradient strengths as due to the inherent longer TE distortions and signal drop-outs are much more severe than in EPI BOLD imaging. Applying single refocusing DTI sequences [7] provides additional TE shortening while preserving the image quality.

References

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