Millimeter analytical Q-ball fiber density function for a better separation of fiber populations at 7T

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Introduction

Diffusion-weighted imaging has become an established technique to investigate the anatomical connectivity of the human brain and remains the unique method available today for *in vivo* studies [1]. During the last decade, many acquisition schemes and post-processing methods have been developed using data at clinical field strengths (1.5T and 3.0T) to infer the local anisotropy of the brain tissue relying on acquisitions with voxel resolutions generally not better than 2mm isotropic. Performing diffusion-weighted acquisitions at high field is challenging because spin echo based echo-planar pulse sequences are highly sensitive to both B1 and B0 inhomogeneities. Moreover, the decrease of the T2 relaxation times observed at high field imposes the use of strong gradients in order to compensate for the loss of SNR due to the presence of the diffusion gradient pulses which limit the minimum possible echo time. Few studies have been published using high field 7T systems in the literature [2-5].

The purpose of this work was to demonstrate the feasibility of diffusion-weighted imaging at ultra-high field (7T) with a true millimeter resolution within a reasonable acquisition time. We also demonstrate the possibility of using b-values for performing high angular resolution diffusion imaging (HARDI) such as Q-ball imaging [6].

Methods

The data were acquired on a Siemens 7T Human MRI system (Siemens, Erlangen), equipped with a gradient insert coil dedicated to head studies (80mT/m, 333T/m/s), and an 8 channel transmit/receive head coil. A single-shot echo-planar spin echo pulse sequence was used endowed with a standard Stejskal-Tanner diffusion module [7]. The acquisition was performed on an healthy volunteer at a b-value of 1400s/mm². The acquisition parameters were as follows: TE=72ms, TR=28s, matrix 192x192, FOV=192mm, slice thickness TH=1mm, 88 slices, partial Fourier 5/8, A/P phase direction, read bandwidth RBW=1736Hz/pixel, 64 uniformly distributed orientations, echo-spacing 0.64ms, 2 repetitions. The field of fiber orientation distribution functions (fODF) was evaluated using the sharpening deconvolution transform (SDT) of the diffusion Q-ball reconstruction proposed in [8][9] relying on the decomposition of the ODFs on a basis of spherical harmonics. The maximum spherical harmonic order was set to 6 and the regularization Laplace-Beltrami factor was set to 0.006. fODFs were estimated using the super constrained resolution technique proposed in [10], and represented using spherical meshes scaled according to the probabilities evaluated at 1000 different points uniformly distributed over the sphere. A millimeter gradient echo acquisition was also performed to get an anatomical T2*-weighted reference with the following parameters: TE=30ms, TR=6.51s, matrix 192x192, FOV=192mm, TH=1mm, 120 slices, GRAPPA factor 2, RBW=30Hz/pixel, flip angle 65°.

Results and Discussion

Figures (a)-(b) depict the direction encoded color maps processed from the diffusion tensor model. It is important to emphasise that few eddy current artifacts can be observed at the boundary of the brain, despite the use of a diffusion module with a single refocusing pulse. This indicates excellent shielding of the gradient insert coil with correspondingly low eddy currents. Figure (d) shows the fiber ODFs field corresponding to the yellow rectangular area drawn on the color and T2* maps given in figure (b) and (c). Q-ball fODFs depict single lobes in regions endowed with single populations (corpus callosum, pyramidal pathways) and present several lobes when corresponding to regions of fiber crossing. The improvement of the spatial resolution clearly allows three populations to be distinguished which correspond to the optical tract with fibers oriented along the antero-posterior direction (green color) surrounded by two thin populations of fibers oriented along the head-feet direction (blue color). This high resolution structural organization of the fibers could not be easily extracted from standard 2mm isotropic data at lower 1.5T or 3.0T fields.

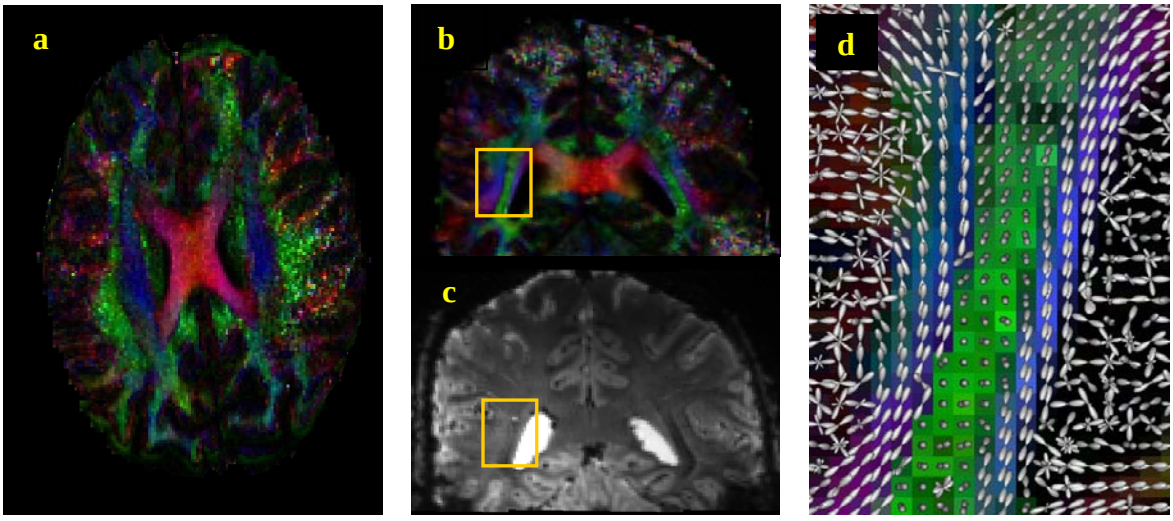

Figure (a)(b) *axial and coronal direction encoded color maps processed from a millimeter isotropic HARDI acquisition performed on a human subject at 7T and b=1400s/mm²*
Figure (c) *millimeter T2*-weighted gradient echo data*
Figure (d) *Fiber ODF field processed from the analytical SDT Q-ball mode* on the yellow box

We have demonstrated the possibility to realize diffusion-weighted imaging with a true millimeter isotropic resolution on a human 7T MRI system, which is not possible with a sufficiently good SNR on clinical human 3T MRI systems. Many clinical studies will benefit from this drastic improvement of the spatial resolution in order to explore smaller structures in the brain such as the small sub-cortical white matter fiber bundles.

The concepts and information presented in this paper are based on research and are not commercially available.

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