Optimized DTI for fibre bundles of known predominant orientation

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Introduction

The aim of this work is to scale the b-value optimally depending on the fibre direction. Usually the b-value is constant for all diffusion gradient directions. In regions where an a priori knowledge of the predominant fibre direction exists, e. g. spinal cord, variable b-values could be applied to optimize overall signal to noise ratio.

In the past, investigators mainly focused on optimizing the gradient sampling scheme [1] whereas the purpose of this work is to minimize the relative error of the diffusion tensor projection in the examined direction $|\Delta D|/D$.

If the logarithm of the signal is plotted against the b-value the slope of the resulting straight line represents D. Since the relative error of D is independent of its size, it is possible to consider the product of the b-value and D as a parameter for optimization. To find the optimal set of direction-dependent b-values for a chosen gradient sampling scheme the best possible b·D is determined and it is assumed that the diffusion tensor is approximately known from earlier measurements.

Methods

The logarithm of the signal and the relative bias and standard deviation of the slope are investigated by Monte-Carlo simulations as described in [2] (repetitions = 1000, averages = 20, signal to noise ratio = 4). It is assumed that the diffusion tensor is prolate with a fractional anisotropy (FA) of 0.7, an apparent diffusion coefficient (ADC) of $0.7 \cdot 10^{-9}$ m^2/s and the principal eigenvector runs parallel to the magnetic field lines.

The direction-dependent b-values were implemented in a SE-EPI diffusion sequence. Diffusion weighted images of the spinal cord with a reduced FOV [3] were acquired on a 1.5 T system (Avanto, Siemens Medical Solutions, Erlangen, Germany) using a dual gradient sampling scheme ((1 1 0), (1 -1 0), (1 0 1), (1 0 -1), (0 1 1), (0 1 -1)). Parameters: FOV = 200 x 50 mm², matrix = 120 x 30, TE = 60 ms, slice thickness = 2 mm, averages = 30, TR = 3 s, partial Fourier factor = 5/8, bandwidth = 758 Hz/Px. The b-value was set to 205 s/mm² for the first four gradient directions and 500 s/mm² for the fifth and the sixth gradient direction. The cerebrospinal fluid (CSF) was suppressed with a global inversion recovery pulse (TI = 1.25 s).

Results

Figure 1a shows a Monte-Carlo simulation where the logarithmic signal is plotted versus b·D. If the chosen b·D is too small the determination of the slope is instable. If the chosen b·D is too large the slope is biased by the background noise. Between both mentioned regions a third region exists where the determination of the slope is stable. In Figure 1b the simulated relative bias and standard deviation of the slope are plotted versus b·D. The standard deviation of the slope decreases whereas its relative bias increases with increasing b·D. Figure 2 shows an unweighted spinal cord image as well as two diffusion-weighted images and the corresponding gradient directions. The signal of the spinal cord is nearly identical in both diffusion-weighted images because direction-dependent b-values are used. The acquired images are of good quality and the presented FA colour map generated with NeuroQLab (MeVis, Bremen) (Figure 2) reflects the main fibre orientation correctly.
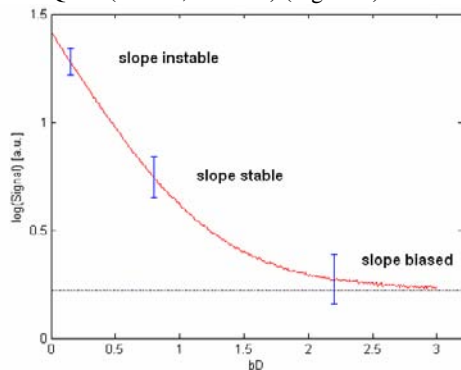

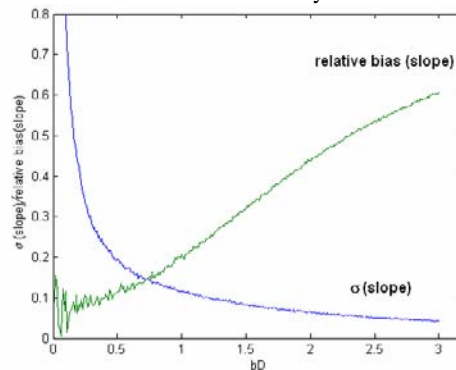**Figure 1a:** Logarithm of signal against b·D and the mean background noise signal.

Figure 1b: Standard deviation and relative bias of the slope against b·D.
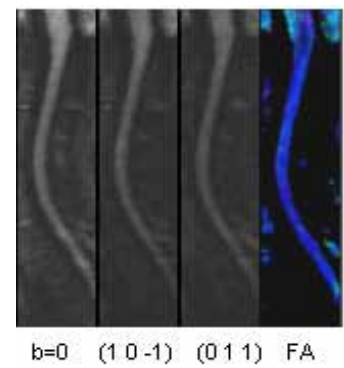

Figure 2: Spinal cord images and FA colour map.

Discussion

In order to find direction-dependent b-values the optimum of the product b·D can be determined. To find this optimum b·D the standard deviation and the bias of the slope have to be considered. Simulations suggest that a minimum exists if the weighted sum of the standard deviation and the relative bias of the slope is taken into account.

Because of its high ADC the CSF displays an artificial anisotropy. To avoid this effect the CSF has to be suppressed by an Inversion Recovery technique. An advantage of this suppression is the avoidance of partial volume effects. The effect of differences in the assumed values of FA and ADC has to be investigated in future research. The described method of direction-dependent b-values can be useful for investigations of other regions with well known fibre orientation such as corpus callosum [4] or muscle fibres.

References

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