Optimization of DTI Imaging Parameters Using Prior Information of Fiber Orientation

W. Gao[1], H. Zhu[2], H. An[3], and W. Lin[3]

[1]Biomedical Engineering, University of North Carolina-Chapel Hill, Chapel Hill, North Carolina, United States, [2]Biostatistics, University of North Carolina-Chapel Hill, [3]Radiology, University of North Carolina-Chapel Hill

Introduction

The aim of this study was to develop a new method to determine optimal imaging parameters for diffusion tensor imaging (DTI). The accuracy and precision of DTI experiments depend on both the choice of the imaging parameters and the modeling of noise propagation in tensor estimation process. Previous studies have been either focused on the signal acquisition without considering changes of noise resulted from the logarithm transform of the magnitude signal and its propagation in tensor estimation [1] or trying to optimize the noise performance in estimation [2] while not considering the signal-to-noise ratio (SNR) in acquisition process. In this work, we propose to combine both of these two processes during the optimization processes. Additionally, information on fiber orientation distribution is also taken into account during the optimization processes. Currently, diffusion encoding scheme is usually chosen to cover the whole sample sphere uniformly. In the human brain especially in the pediatric brain, however, the orientation distribution of major WM fibers may have a specific pattern with the majority of fibers oriented in several well separated cone areas (Fig. 1). As a result, the diffusion encoding scheme could efficiently sample those "densely oriented cone areas" in a shorter data acquisition, leading to the efficient use of imaging acquisition time, which is crucial for pediatric imaging.

Methods

The proposed optimization scheme consists of three steps. A new design criterion was developed according to two estimation methods: weighted least square (WLS) and least square (LS) estimates [3, 4]. The approach proposed by Alexander and Barker's [1] was adapted to find the optimal TE, width and separation of diffusion pulses, which have been incorporated into our design criterion, at a specific b-value based on a pulsed-gradient spin-echo (PGSE) sequence with echo-planar imaging (EPI) read out. Finally, the simulated annealing algorithm was employed to optimize the design criterion to find optimal b-value and diffusion gradient directions for a known tensor field. Monte-Carlo simulations were carried out to evaluate the proposed optimization scheme. Synthetic data were generated to simulate two different fiber orientation distributions: a) fibers orientated in only 1 cone area (with a diverging angle of 20^0) and b) fibers orientated in 3 well separated cone areas. Using these predefined tensor fields as prior information, optimal b-values (at which settings of TE, pulses width, pulses separation already optimized) and gradient directions schemes were found through the optimization process. The optimal gradient schemes were compared with the conventional schemes at different b-values considering four different baseline SNRs (16, 24, 34, 57) at each b-value. For each of fiber distributions, we also considered three different imaging acquisition schemes that consists of M b=0 images and N gradient directions with b>0: M=1/N=6; M=2/N=12; M=5/N=30. Bias and standard deviation of the six independent tensor elements were used as performance indices.

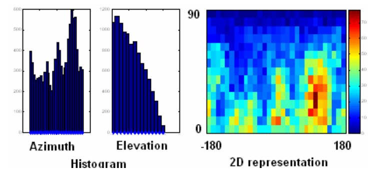

Fig.1. Fiber orientation distribution in a 1-year-old (FA>0.4)

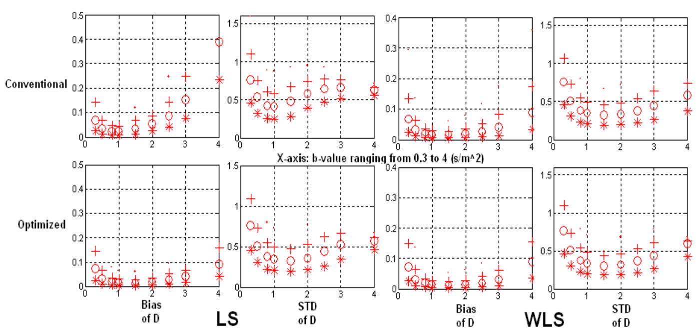

Fig.2. Results of Bias (1, 3 column) and standard deviation (2, 4) of **D** from the conventional (upper row) and optimized schemes (bottom row) for both LS (first 2 columns) and WLS estimation (last 2 columns) (One fiber cone area case with M/N=2/12).

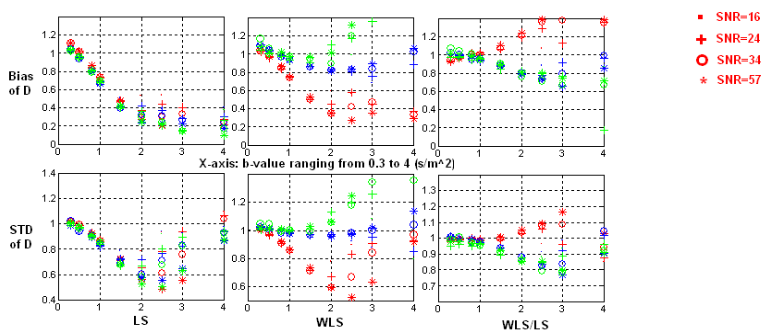

Fig.3. Results of single fiber cone area case. Red, blue and green color represents M/N=1/6, 2/12, and 5/30 respectively. The first 2 columns are ratio of Bias of tensor elements (top row) and standard deviation (bottom row) of results from optimized gradient scheme over those from conventional scheme. The third column shows the ratio of these two measurements from WLS and LS optimization.

Results

The results based on a single fiber cone area case with M/N=2/12 are shown in Fig.2. Both the bias and standard deviation of tensor elements (STD) from the conventional scheme using LS square estimation (first 2 columns in upper row) agrees with Alexander and Barker [1], showing that optimal b-value is around 1 s/m^2. With the proposed optimization approach, in addition to the reduction of these two indices at each b-value, a much wider range of optimal b-values is observed for both bias and STD for LS estimation when compared to that obtained using the conventional scheme. Similar results are also observed in M/N=1/6 and 5/30 cases. Nevertheless, the differences between conventional and the proposed approach become less using WLS. More detailed comparison regarding the advantages of the proposed optimization approach vs the conventional approaches is shown in Fig. 3 where the ratios (proposed/conventional approaches) of the bias and STD are shown. The LS optimization (first column) shows that it generally reduces bias and STD by about 50% and 30%, respectively, within the optimal b-value range regardless of different M and N. For WLS (second column), this improvement decreases from about 50%/30% (Bias/Standard deviation) for M/N=1/6 case to less than 5% (both) for M/N=5/30. Nevertheless, the comparison of optimization results of WLS against LS (third column) shows a general better performance of WLS optimization except in M/N=1/6 case. The results of the three fiber cone area case show similar behaviors although a reduction in absolute improvement percentage is observed.

Discussion

The proposed optimization approach accounts for both the inherent MRI noise and its propagation in tensor estimation process. As evident, it is of critical importance to optimize the imaging parameters as well as diffusion gradient directions when LS estimation is employed. WLS estimation, however, is less sensitive to change of b-values although the proposed optimization continues to reduce estimation errors. In practical imaging acquisition, it is feasible to construct a brain atlas of DTI using currently existing data, allowing the identification of the fiber distribution patterns in human brains which in turn can be used as the prior information for the proposed optimization scheme.

References

[1] Alexander and Barker, *NeuroImage*, 27,357-367, 2005. [2] Skare et al, *JMR*, 147, 340-352, 2000. [3] Basser, et al, *JMR*, 103(B), 247-254, 1994. [4] Zhu et al, *JASA*, in press.