Non-uniform distribution of diffusion gradient directions using preferred diffusion tensor orientations in the human brain

J. Siero[1], and H. Hoogduin[1]

[1]BCN Neuro Imaging Center, University Medical Center Groningen / University of Groningen, Groningen, Groningen, Netherlands

Introduction

Diffusion tensor imaging usually employs uniformly distributed gradient direction schemes. This is based on the work of Jones et al. [1] who suggested to evenly spread the gradient directions in space because a priori spatial information about the local diffusion profiles in the human brain is unknown. In this study we focus on the possibility of using non-uniform sampling schemes. This is done in three steps. First, diffusion tensor orientations in six human subjects were investigated for consistent preference in tensor orientation. This resulted in a coherent non-uniform distribution of tensor orientations in the brain. Second, we adapted the electrostatic repulsion method of Jones et al. [1] to take into account this non-uniformity of the distribution. The idea was to sample more in directions of high anisotropy to get a better estimation of the tensor. The resulting non-uniform 60 direction scheme is compared to the Jones60 scheme in five subjects.

Methods & Results

All measurements were preformed on a 3T Philips scanner. For the first part of the study we used data from six subjects using a single shot spin-echo EPI sequence. Sequence parameters were: TR=6s, TE=77ms, SENSE factor=3, 60 uniformly distributed gradient directions based on the Jones60 scheme [1] with b=800s/mm^2 and the average of 7 non diffusion weighted images and 51 slices with a resolution of 1.9x1.8x2mm^3. Data with two different fat shift directions were acquired: along Anterior Posterior in the Posterior direction (APP) and APA. This combination was acquired twice (run1=APP1 & APA1 and run2=APP2 & APA2). Scan time per dataset was around 7 minutes. Post-processing included Eddy current and motion correction using FSL [2], susceptibility distortion correction using the APP and APA datasets with the software kindly provided by Jesper Anderson [3], brain extraction , co-registration of run 1 and 2 before averaging, diffusion tensor estimation from the averaged dataset using the diffusion toolbox of FMRIB [4], and finally Bayesian estimation of diffusion parameters resulting in distributions of fractional anisotropy (FA) value and principle eigenvector orientation for each voxel. For each subject a plot showing the distribution of principle eigenvectors was obtained for tensors with a FA>0.25. The distributions were co-registered by applying the rotational parameters of the rigid body co-registration which was obtained by aligning all subjects to a single subject. Figure 1 shows the normalized result. Clearly there are hotspots which indicate consistent tensor orientation over subjects. The dominant hotspots correspond to the left-right direction in the human head. In addition there is also some preference for the anterior posterior direction.

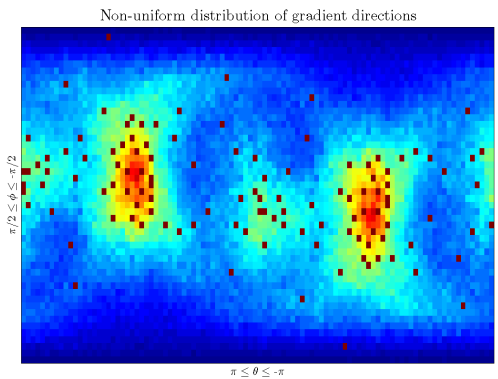

Figure 1: Coherent fiber orientations in six subjects and non-uniform gradient direction scheme.

Next we adapted the electrostatic repulsion method in such a way that tensor directions were attracted to the dominant directions. The resulting directional scheme is also shown in figure 1 and was implemented on the scanner. Finally, this scheme and the Jones60 scheme were used in five additional subjects. The scan parameters and data analysis were similar to the above with the exception that only one run was done for each directional scheme. One subject was excluded due to excessive head motion during scanning.

The use of Bayesian estimation of diffusion parameters allowed us to study if there were any changes in FA and uncertainty in FA. This is shown for one subject in figure 2 and 3, respectively. Similar results were obtained in the other three subjects. The figures show the average FA and uncertainty in FA in three different regions of interest (ROIs) which were manually segmented. Only values with an FA>0.25 were included in the average. Clearly, there is a difference between the two directional schemes. In general, FA values increase using the non-uniform scheme, dominantly in the right-left direction and to a lesser extend in the other two orientations. The error in the measured FA value decreases for the left-right and anterior-posterior direction and increases for the inferior-superior direction. .

Discussion

We studied the effect of using a non-uniform sampling scheme in DTI to take into account the non-uniformity of fiber orientations in the human brain. The fiber orientation that is most dominant in the head is the left-right orientation followed by the anterior-posterior direction. Somewhat surprising there was no coherence over subjects for the inferior-superior direction. The effect of adjusting the gradient directional scheme to the preferred orientations lead to a reduced error in the FA estimates for the left-right and anterior-posterior direction. This is what one would expect because the accuracy in the measurement is increased in these directions. Similarly, the increased FA error for the inferior-superior direction can be explained by the reduced number of samples in this direction. The mean FA value increased slightly for all directions. As expected, the main effect is again seen for the right-left direction. This work shows that non-uniform gradient direction schemes lead to an increased accuracy in the estimated FA value for dominant fiber orientations in the brain. The lack of coherence in the inferior-superior orientations remains an open question.

References

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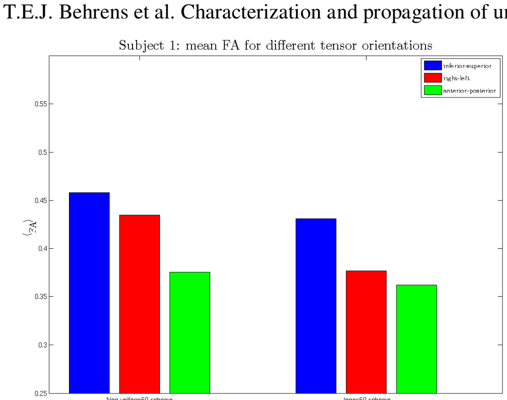

Figure 2: Mean FA for different tensor orientations

Figure 3: Error in FA for different tensor orientations