Resolving multiple fiber crossings with high *b*-value and high angular resolution *q*-ball imaging

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TARGET AUDIENCE

Researchers in the field of high angular resolution diffusion MRI. The work has potential applications in tractography and structural connectivity analysis.

PURPOSE

In principle, increasing the diffusion weighting (*b*-value) results in improved angular specificity of the diffusion orientation distribution function (ODF) and consequently enhanced resolution of multiple intravoxel crossing fiber populations but at the expense of increased noise in the ODF. The latest generation of human diffusion "Connectome" MRI scanners equipped with dedicated gradient hardware are capable of achieving *b*-values > 10000 s/mm^2 while maintaining high imaging resolution with sufficient signal-to-noise ratio (SNR). In this study, the purpose was to quantify how increasing the *b*-value and angular sampling resolution affects the capability to detect multiple fiber crossings in the human brain using *q*-ball imaging (QBI)[1].

METHODS

The study protocol was approved by the local institutional review board. Diffusion imaging data were acquired from a healthy adult subject using a Siemens 3T "Connectome" scanner with 300 mT/m gradient system and 64-channel brain array coil. Three QBI diffusion-sampling scenarios were considered: i) *b*=5000 with 128 directions, ii) *b*=10000 with 128 directions and iii) *b*=10000 with 256 directions. The diffusion sampling directions were generated using the electrostatic repulsion method[2]. All diffusion acquisitions were 2D spin-echo EPI with identical imaging parameters: resolution 1.5 mm isotropic (6/8 phase partial Fourier) / iPAT factor 3 / flip angle 90° / TE 57 ms / TR 8800 ms. The data were corrected for gradient nonlinearity off-line and the FSL[3] tool "eddy" was applied to correct for eddy current artifacts and to perform motion correction. A standard diffusion tensor fitting was performed using Diffusion Toolkit[4] to identify a multiple-fiber crossing in the centrum semiovale region by using the fact that such crossings will appear darker in the fractional anisotropy (FA) map. The QBI ODF reconstruction was performed by using the spherical harmonics (SH) expansion method[5]. The order of the SH expansion was eight, resulting in 45 SH basis functions. Laplace-Beltrami regularization was applied in the SH fitting with regularization parameter set to 0.01. The maximum of each ODF was scaled to unity and three dominant peak directions (peak #1, #2, and #3) of the ODFs were identified and sorted according to ODF amplitude. The amplitude of the peak #3 relative to the ODF baseline (minimum) was used to quantify the sensitivity of detecting a three-fiber crossing. The ODF reconstructions and visualizations were implemented using MATLAB (R2012a, The MathWorks Inc.)

RESULTS

Figure 1(A) shows a coronal slice of the FA map that was used to select an ROI for the fiber crossing analysis. Figure 1(B) shows the ODFs and peak #3 amplitudes resulting from the different diffusion sampling scenarios. Qualitatively, the results show that the "sharpness" of the ODF clearly increases with increasing *b*-value and angular sampling resolution, resulting in more robust delineation of the fiber crossing. Quantitatively, the amplitude of the ODF peak #3 also increases and shows a more coherent spatial pattern with higher *b*-value (and to a lesser extent with higher angular resolution).

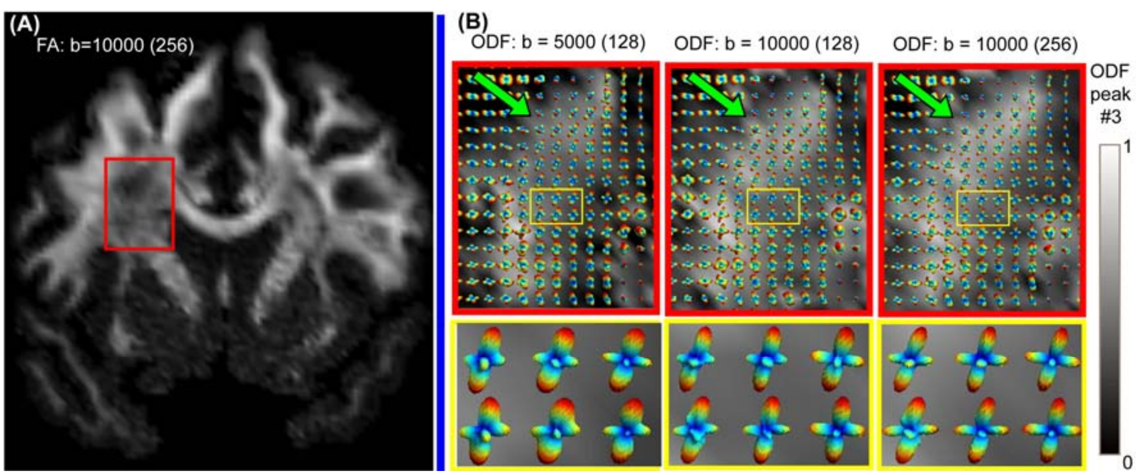

Figure 1 (A): The FA map used to select a ROI (red box). **(B):** ODFs from the ROI overlaid on the peak #3 amplitude maps for different QBI acquisitions. The yellow box shows a further close-up region to display the detailed shapes of the ODFs. The green arrows highlight the region in which the amplitude of the ODF peak #3 shows largest amplitude differences between the QBI sampling schemes.

DISCUSSION

Although the inherent image SNR is higher in the *b*=5000 /128 direction case, the *b*=10000 /128 direction ODF shows an improvement in the "fiber crossing contrast" both qualitatively and quantitatively. Further improvements are seen from increasing the number of directions at *b*=10000 but further investigation is required to determine whether the improvement in the *b*=10000 / 256 case results from the averaging effect (SNR) of having more directions or from the actual higher angular sampling resolution. We should also note that the ODF reconstructions are conditioned on the selection of the regularization parameter. The optimal selection of this parameter may depend on the SNR, but here an identical and relatively conservative value was assumed across all conditions to make the comparison robust.

CONCLUSIONS

With high *b*-values achievable by the latest human diffusion MRI scanners, the increased sharpness of the ODFs potentially offers a way to improve resolving complex intravoxel fiber crossings using simple model-free methods such as the regularized SH expansion QBI reconstruction.

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