Reduce Encoding of Diffusion Spectrum Imaging with Cross-term Correction

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Introduction

Diffusion spectrum imaging (DSI) can be used to define complex fiber orientations accurately [1, 2]. However, the scanning procedure is time-consuming under current 515 data sampling scheme. In this study, we developed a reduced encoding scheme based on the property that diffusion echo signal is spherical symmetry, i.e. E(-**q**)=E(**q**). 515 encoding points were reconstructed from hemi-spherical points in q-space, i.e., 298 points. Diffusion cross-term was calculated and eliminated from diffusion sequence [3]. Three phantom models, coherent fiber, 45°, and 90° crossing fibers, were investigated and showed angular error of 0º, 42.05°±1.97°, and 91.38°±4.78° respectively. Applying this reduced encoding scheme and cross-term correction, we demonstrated that half-spherical encoding points is feasible for DSI encoding while preserving fiber orientations.

Materials and Methods

Three phantom models, coherent fiber, 45°, and 90° crossing fibers, were designed and studied in this research. The phantoms consisted of water-filled, well-organized plastic capillaries with I.D./O.D.=50/350 µm [2]. Half-spherical 298 encoding points in q-space were acquired at 3T Medspec/Biospec MRI system (Bruker, Germany). A diffusion stimulated echo sequence was used with in-plane resolution=688×688 μm^2, slice thickness=3.5 mm, δ/Δ = 6/250 ms, and G_{max} = 11.2 G/cm which yielded to b_{max} = 8000 s/mm^2. In addition, complete 515 encoding points in q-space was acquired for reference.

515 encoding points were reconstructed from hemi-spherical points in q-space, i.e., 298 points, with applying cross-term eliminator in prior to DSI analysis. Diffusion cross-term was eliminated by applying spline interpolation to the estimation of E(**q**) from E(q+Δ**q**), where Δ**q** was induced by imaging gradients and could be estimated from diffusion sequence. DSI analysis was based on the relationship that the echo signal E(**q**) and diffusion probability distributed function (PDF) P(**r**) were a Fourier pair, i.e., P(**r**) = FT[E(**q**)]. The orientation distributed function (ODF), which reflected distribution of fiber orientations within each voxel, was determined by $\int P(\mathbf{r})\, r^2\, dr$ along each radial direction. The primary ODF was defined by local maximal probability, which pointed out the fiber orientations. Calculated with the vertices of 16-fold tessellated icosahedron (n=2562), ODF gives an angular resolution of 4°.

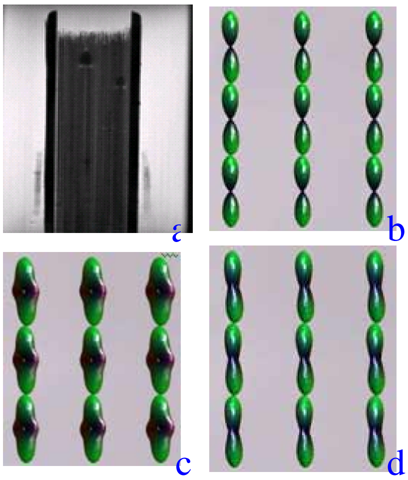

Fig. 1. DSI of phantom model with coherent fibers. (a) T2-weighted image. (b) ODF of standard 515 points. (c) ODF of 298 points without cross-term correction. (d) ODF of 298 points with cross-term correction

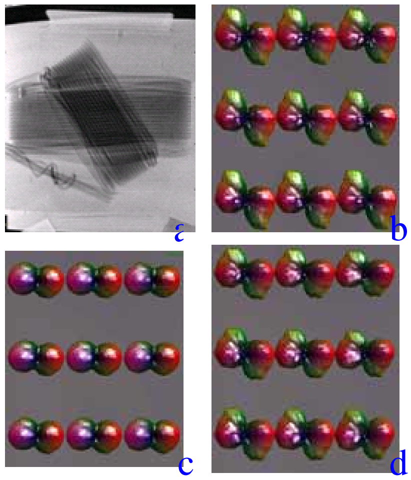

Fig. 2. DSI of phantom model with 45° crossing angle (a) T2-weighted image. (b) ODF of standard 515 points. (c) ODF of 298 points without cross-term correction. (d) ODF of 298 points with cross-term correction

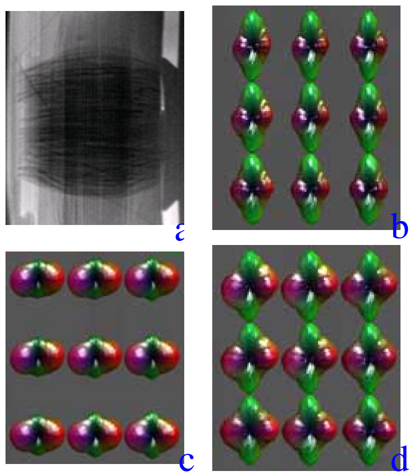

Fig. 3. DSI of phantom model with 90° crossing angle (a) T2-weighted image. (b) ODF of standard 515 points. (c) ODF of 298 points without cross-term correction. (d) ODF of 298 points with cross-term correction

Results

Figure 1 shows the results of coherent phantom model. ODF of 515 encoding points was served as a reference (Fig. 1b). Figure 1c and 1d show the ODF reconstructed from 298 encoding points without and with cross-term correction respectively. Uncorrected cross-term resulted in a pseudo orientation from reduced encoding points (Fig. 1c). Figure 2 shows the results of phantom model with 45° crossing angle. The fiber angle acquired from standard encoding scheme and from reduced encoding scheme with cross-term correction is 44.00°±1.98° (Fig. 2b) and 42.05°±1.97° (Fig. 2d). Without cross-term correction, reduced encoding scheme is incapable of mapping 45° fiber crossing (Fig. 2c). Figure 3 shows the results of 90° crossing model from standard 515 encoding scheme and 298 encoding scheme without and with cross-term correction. The angle are 90.67°±2.80° (Fig. 3b), 91.38°±4.78° (Fig. 3c), and 90.25°±2.63° (Fig. 3d) respectively.

Conclusion

Cross-term induced from imaging gradients can be eliminated from symmetry encoding points.[4] By using half spherical encoding points to reconstruct DSI, cross-term might affect the angular accuracy and result in pseudo orientations. Cross-term effects from imaging gradient are dissimilar in 3 encoding directions. The results showed that phase imaging gradient has the less cross-term effect. To minimize post-processing error, half-spherical encoding scheme is suggested to apply in this phase encoding direction. Though the post-processing method is useful toexclude cross-term from imaging gradients, cross-term from eddy currents might hardly be eliminated. Therefore, imaging sequence such as twice-refocus spin echo sequence is suggested [5]. In conclusion, this study shows that reduced encoding scheme with cross-term correction is feasible to reduce DSI acquisition time to 58% while preserving fiber orientations.

Acknowledgements

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Reference

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