Analysis of Fiber Reconstruction Accuracy in High Angular Resolution Diffusion Images (HARDI)

L. Zhan[1], A.D.Leow[1], S.Zhu[2], M.C. Chiang[1], M. Barysheva[1], A.W. Toga[1], K. L. McMahon[3], G. I. de Zubicaray[3], M. J. Wright[4], P.M. Thompson[1]

[1]Laboratory of Neuro Imaging, Department of Neurology, UCLA School of Medicine, UCLA, Los Angeles, CA
[2]Department of Mathematics, UCLA, Los Angeles, CA
[3] University of Queensland, Functional MRI Laboratory, Centre for Magnetic Resonance, Brisbane, Australia
[4]Queensland Institute of Medical Research, Brisbane, Australia

Introduction: High angular resolution diffusion imaging (HARDI) is a powerful extension of MRI that maps the directional diffusion of water in the brain. With more diffusion gradients and directions, fiber directions may be tracked with greater angular precision, fiber crossings can be resolved, and anisotropy measures can be derived from the full fiber orientation density function. To better reconstruct HARDI, we recently introduced the tensor distribution function (TDF), which models multidirectional diffusion as a probabilistic mixture of all symmetric positive definite tensors [1]. The TDF overcomes limitations of several HARDI reconstruction methods (e.g., q-ball imaging, DOT, PAS) which restrict all component fibers in a voxel to have the same anisotropy profile. The TDF models the HARDI signal more flexibly, as a unit-mass probability density on the 6D manifold of symmetric positive definite tensors, yielding a TDF, or continuous mixture of tensors, at each point in the brain. From the TDF, one can derive analytic formulae for the orientation distribution function (ODF), tensor orientation density (TOD), and their corresponding anisotropy measures. Because this model can accurately resolve sharp signal peaks in angular space where fibers cross, we studied how many gradients are required in practice to compute accurate orientation density functions, as more gradients require longer scanning times. In simulated two-fiber systems with varying Rician noise, we assessed how many diffusion-sensitized gradients were sufficient for (1) accurately resolving the diffusion profile, and (2) measuring the exponential isotropy (EI), a TDF-derived measure of fiber integrity that exploits the full multidirectional HARDI signal.

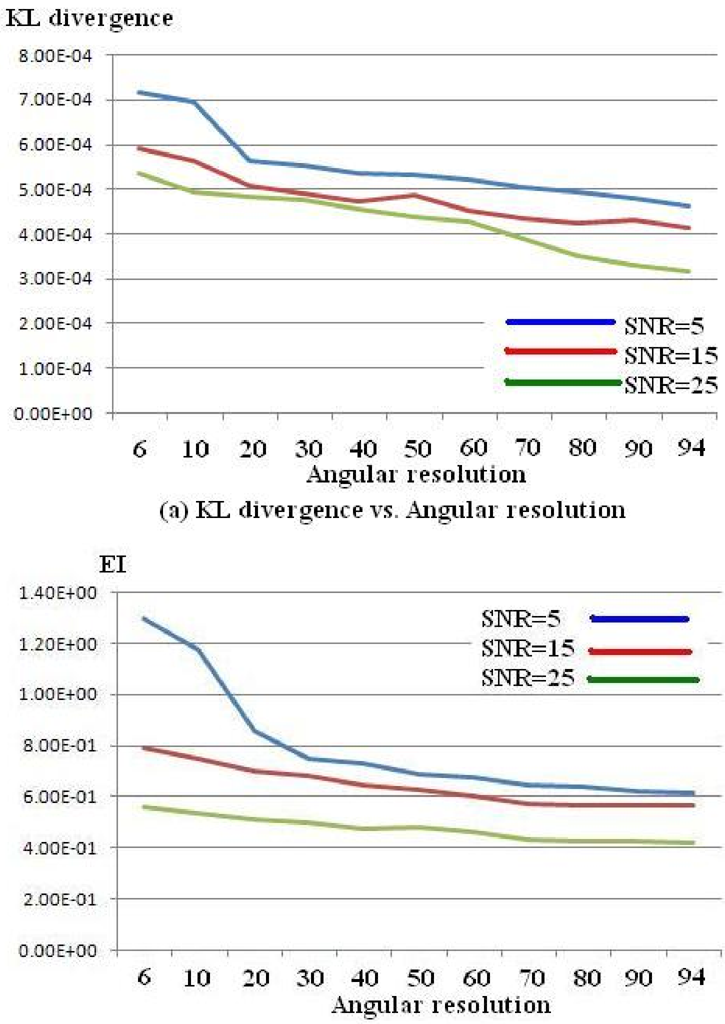
Methods: We created various models of two-fiber systems, crossing at 90 degrees with equal volume fractions and eigenvalues typical for white matter [1]. Data were sampled at 94 points evenly distributed on the hemisphere using a Partial Differential Equation (PDE) based on electrostatic repulsion [2]. Rician noise with different amplitudes (SNR=5, 15, 25) was added. Several angular sampling schemes, with between 6 to 94 directions, were sub-sampled from the original 94 angular points to maximize the total angular energy [3]. Using these optimized subsets of angular points, we subsampled the original HARDI94 data, and assessed how accurately the diffusion profile could be reconstructed, using the Kullback-Leibler (KL) divergence to measure the reconstruction accuracy of the ODF derived from the subsampled schemes.

Results: As expected, reconstruction error decreases with increasing SNR and when using more scanning directions (Figure 1(a)). The reconstruction accuracy of a 90-direction low-SNR sequence is about the same as a 7-direction sequence with five times the SNR. When SNR is low, adding directions has greater benefit. EI, a measure of fiber integrity, decreases with increasing angular resolution, stabilizing by ~70 directions (Figure 1(b)). This is in line with the finding that fractional anisotropy, derived from DTI, is underestimated when fibers cross.

Conclusions: HARDI scanning provides more accurate diffusion reconstruction than DTI.. To optimize accuracy of diffusion reconstruction the derived anisotropy measures, it is more time-efficient to acquire more angular samples rather than repeatedly sample the same directions for purposes of signal averaging.

References: [1]. Leow AD et al. The Tensor Distribution Function, Magnetic Resonance in

Medicine 2008.
[2]. Jones et al., MRM 42(3):515-25(1999)
[3]. Zhan L et al. (2008). *How Many Gradients are Sufficient in High-Angular Resolution Diffusion Imaging (HARDI)?* MICCAI DTI Workshop, 2008.



(a) KL divergence vs. Angular resolution

(b) EI vs. Angular resolution

Figure 1