Bootstrap Tractography using Multimodal Fiber Orientation Data from High Angular Resolution Diffusion Imaging

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Introduction:

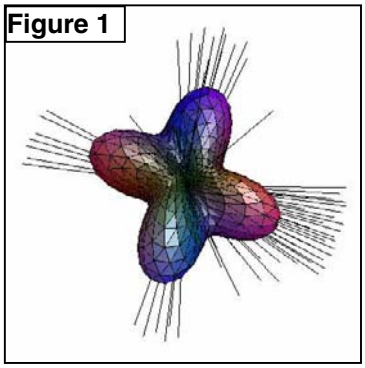
The goal of tractography is to delineate specific white matter pathways based on the observed diffusion patterns of water. High angular resolution diffusion imaging (HARDI) surpasses diffusion tensor imaging (DTI) by resolving crossing fiber populations. State of the art fiber tracking methods rely on uncertainties in the propagators for each fiber tracking step to provide a probabilistic framework to analyze these trajectories. For DTI, the direction of the largest eigenvector is typically used but this information is insufficient to deal with crossing fiber populations and information inherent in the minor eigenvectors cannot be reliably associated with directions of crossing fiber bundles. Probabilistic methods can be used to accidentally sample alternate fiber populations with DTI, but with the HARDI reconstruction, crossing fiber bundles can be sampled probabilistically and used as physically meaningful multiple propagators. This study uses the bootstrap method to perform probabilistic fiber tracking with the HARDI reconstruction. Bootstrap analysis is a model independent way of characterizing the uncertainty in diffusion MR from a variety of sources [1]. Previous studies have used bootstrap DTI fiber tracking to incorporate data uncertainty into generated fiber tracks [2]. For this work, a bootstrap HARDI fiber tracking algorithm was implemented and its performance evaluated relative to DTI in regions of intersecting white matter pathways.

Methods:

Whole-brain HARDI was performed on a normal adult volunteer using a 3T Signa EXCITE MR scanner and an 8-channel phased array head coil (GE, Milwaukee, WI). Images were acquired with a single-shot spin echo EPI sequence (TR/TE=6.2s/83ms, NEX=1, SENSE factor 2) at 1 x 1 x 2 mm voxel resolution using 55 diffusion-encoding gradient directions at b=3000 s/mm^2. The 14 minute whole-brain HARDI acquisition was sequentially repeated 3 times. For each voxel through which the fiber trajectories pass, a complete diffusion-weighted data set is chosen by randomly sampling from each of the 3 bootstrap acquisitions. Reconstruction of the fiber orientation distribution function (ODF) of each bootstrapped diffusion set was performed using the q-ball method with a spherical harmonic basis truncated at order 4 [3]. Multimodal fiber orientations corresponding to the major peaks of the ODF were determined using a gradient descent algorithm. The ODF peak with orientation closest to the fiber track's previous trajectory was chosen to propagate the fiber track through the voxel. Fiber tracks were launched from a user-defined region densely seeded with 27 equally spaced starting points per voxel. The starting voxels are densely seeded to ensure that multiple fiber tracks enter the same voxels. Each trajectory through the common voxels may be different because of a different bootstrap resample. The callosal fiber tracks of Figure 2 were generated with a total of 540 starting points in the body of the corpus callosum. For comparison, DTI fiber tracking was performed using the same starting regions and the same fiber tracking integration method [4].

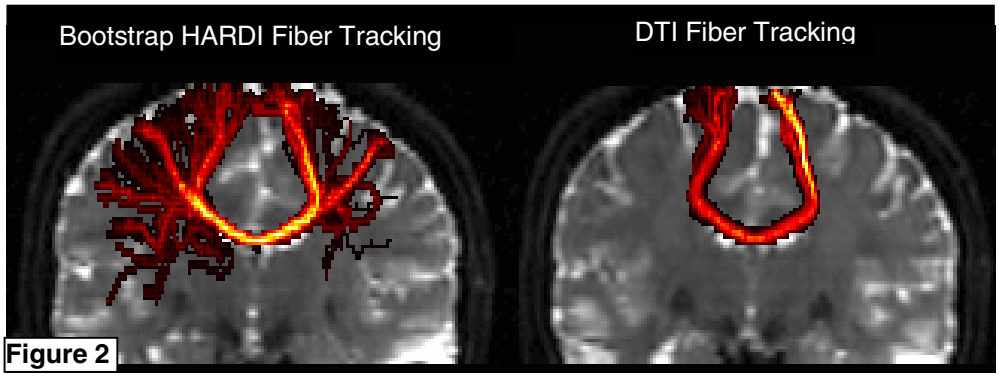
Results and Discussion:

Figure 1 shows an example q-ball ODF from a region of crossing callosal (*red*) and projectional (*blue*) fibers in the centrum semiovale. The multiple line segments indicate the orientation of the q-ball ODF peaks from 1000 bootstrap HARDI reconstructions. The ODF peaks are clustered around the probable fiber orientations. There are fewer than 1000 line segments in the figure because the same ODF node may be the peak location multiple times. Figure 2 shows a coronal maximum intensity projection of bootstrap HARDI fiber tracking and DTI fiber tracking of the corpus callosum. Both sets of fiber tracks were generated using the same starting region in the body of the corpus callosum. The bootstrap HARDI fiber tracks traverse crossing association and projection fibers and radiate throughout the frontal and parietal lobes, matching the known anatomy of these commissural fibers. The DTI fiber tracks were only able to delineate the component of the corpus callosum that projects superiorly, because they are unable to traverse the intersecting projection and association tracts more laterally. Bootstrap HARDI fiber tracking can follow the commissural fibers through these regions of complex white matter architecture using the multimodal intravoxel fiber orientation data available from q-ball reconstruction of HARDI. The HARDI acquisition described herein can be performed within a clinically feasible timeframe; however, bootstrap analysis is not appropriate for routine clinical use as it requires multiple identical acquisitions. It is possible that variants such as the wild bootstrap [5] performed on a single HARDI acquisition may overcome this barrier to routine clinical application of bootstrap HARDI tractography.



Conclusions:

Bootstrap HARDI fiber tracking combines the valuable attributes of accounting for uncertainty in fiber orientation estimates and delineating connectivity in regions of complex white matter architecture.



References:

1) Pajevic, *JMR* 2003:161:1-14.
2) Lazar, *Neuroimage* 2005; 24:524-32.
3) Hess, *Proc ISMRM* 2005, 389.
4) Mori, *Ann Neurol* 1999; 45:265.
5) Whitcher, *Proc ISMRM* 2005, 1333.