Whole-Brain High Angular Resolution Diffusion Imaging within a Clinically Feasible Acquisition Time

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Introduction: Diffusion tensor imaging (DTI) is limited in that it assumes only one fiber orientation per voxel. High angular resolution diffusion imaging (HARDI) refers to the acquisition of large numbers of diffusion directional measurements at *b* values greatly exceeding 1000 s/mm^2. HARDI surpasses DTI by resolving multiple fiber orientations per voxel, enabling the visualization of complex white matter architecture in regions containing crossing fiber tracts. In this study, we demonstrate the feasibility of whole-brain HARDI within a clinically acceptable acquisition time in normal adult volunteers, in patients with traumatic brain injury (TBI), and in patients with agenesis of the corpus callosum (ACC).

Methods: Whole-brain HARDI was performed on five adult volunteers, two TBI patients, and two ACC patients using a 3T Signa EXCITE MR scanner (General Electric, Milwaukee, WI) and parallel imaging (ASSET acceleration factor 2) with an 8-channel phased array head coil. Whole-brain data with 2.2 mm isotropic voxel resolution were acquired in 15 minutes using a single-shot echoplanar spin-echo sequence (TR=8.2s, TE=82ms) with 55 diffusion gradient directions at *b*=3000 s/mm^2. The fiber orientation distribution function (ODF) was reconstructed with three different techniques: (a) q-ball (Tuch, *Magn Reson Med* 2004; 52: 1358-72) using spherical harmonic basis functions (Hess et al., *Proc ISMRM* 2005; 389); (b) spherical deconvolution (Tournier et al., *Neuroimage* 2004; 23:1176-85); and (c) the diffusion orientation transform (Özarslan et al., www.cise.ufl.edu/tech_reports/tr05/tr05-004.pdf). The ODF results were compared to diffusion tensor reconstruction of the HARDI data. The spherical harmonic series was truncated at order 4 for q-ball and spherical deconvolution. For spherical deconvolution, the response function was obtained from the highly collimated fibers at the midline of the splenium of the corpus callosum. The angular probability radius parameter R_0 for the diffusion orientation transform was chosen based on the diffusion time and diffusivity according to the heuristic described by Özarslan et al.

Results: The 15-minute HARDI acquisitions provided excellent image quality in all volunteers and patients, with no significant motion artifacts. All 3 ODF reconstruction methods (spherical harmonic q-ball, spherical deconvolution, and the diffusion orientation transform) enabled visualization of crossing fiber tracts in regions where DTI provided no accurate fiber orientation information. The Figure at left shows representative results from the right periventricular white matter of a normal volunteer containing intersecting association (SLF), projection (CS), and commissural (CC) fiber tracts. The Figure at right shows the corresponding region of an ACC patient. Note that the normal crossing between projection fibers of the CS and commissural fibers of the CC is not present, since there is no corpus callosum. However, the expected crossing between the projection fibers of the CS and the association fibers of the SLF is still identified. In the two TBI patients, HARDI showed evidence of white matter injury in areas of complex white matter architecture not adequately evaluated by DTI.

Discussion: We show that whole-brain HARDI can be performed within a clinically acceptable scan time using a 3T scanner with a multi-channel phased array head coil. The spatial resolution of this 15-minute HARDI acquisition is equivalent to that of most DTI studies. Parallel imaging was employed to ameliorate image artifacts typical for single-shot echoplanar imaging at high field and with strong diffusion-weighting. All 3 ODF reonstruction methods using spherical harmonic basis functions (q-ball, spherical deconvolution, and diffusion orientation transform) yielded qualitatively similar fiber orientation information. The primary limitation of this rapid HARDI acquisition is lower angular resolution than much longer HARDI acquisitions with several hundred diffusion-encoding directions. However, since many fiber tracts of the brain are known to cross at large intersection angles, this 15-minute HARDI acquisition is still capable of effectively visualizing many important regions of complex white matter architecture in the normal brain and in patients with aberrant or injured white matter. Compared to DTI, HARDI improves fiber tracking through intersecting axonal pathways, provides greater resilience to intravoxel partial volume effects due to adjacent fiber pathways with different orientations, and better characterizes white matter disorders in regions of complex fiber architecture.