Improved Whole-Brain Fiber-Tracking Results Using Turboprop-DTI with Less Than 19 Minutes of Scan-Time

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Introduction: Tractography by means of diffusion tensor imaging (DTI) is the first non-invasive technique that can provide estimates of white matter tracts in the brain [1]. Accurate mapping of white matter fiber-tracts in relation to brain pathologies is a goal of critical importance to the neurosurgical community. The accuracy and reproducibility of fiber-tracking results depend heavily on the noise level and amount of artifacts of the DTI images. However, current tractography methods use DTI data acquired with spin-echo echo-planar DTI (SE-EPI-DTI), or variations of it, which suffer from susceptibility-related image distortions, signal loss and pile-up, and image warping due to eddy-currents. Turboprop-DTI is based on multiple-shot fast spin-echo (FSE) and provides images with significantly fewer susceptibility and eddy-current-related artifacts [2]. The goal of this project was to compare the fiber-tracking results obtained from SE-EPI-DTI and Turboprop-DTI data on the same human subjects. It was demonstrated that even after correction of susceptibility and eddy-current-related distortions, tracts produced from SE-EPI-DTI datasets were slightly distorted, and in some cases missing, or terminated early. In contrast, fibers mapped with Turboprop-DTI were undistorted and consistent with known anatomy. Furthermore, tracts produced from two Turboprop-DTI datasets on the same subject contained a high percentage of common voxels. This was not true when comparing tracking results from a Turboprop-DTI and a SE-EPI-DTI dataset, particularly for fibers located near significant field inhomogeneities. Finally, all Turboprop-DTI acquisitions were completed in less than 19 minutes.

Methods: All scans were performed on a 3T GE MRI scanner (Waukesha, WI). High-resolution 3D-MPRAGE images were acquired for all subjects. Two types of SE-EPI-DTI datasets were acquired: SE-EPI-DTI$_{12}$ with 12 diffusion directions and NEX=11, and SE-EPI-DTI$_{138}$ with 138 diffusion directions and NEX=1 [3]. The other scan parameters were: TR=5400ms, TE=71.8ms, FOV= 24cm x 24cm, image matrix=256x256 (after zero-filling). A gradient-echo sequence (GRE) with TE$_1$=7ms, TE$_2$=18.4ms, TR=2000ms, scan time=4:24, was used to create field maps. The total effective scan time for SE-EPI-DTI$_{12}$ and SE-EPI-DTI$_{138}$ (including the time for the GRE sequence) was 18:20 and 18:54 respectively. Two sets of Turboprop-DTI data were acquired with the same scan parameters: TR=5000ms, FOV= 24cm x 24cm, 16 blades, 8 spin-echoes per blade, 5 k-space lines acquired per spin-echo similar to the GRASE sequence, 192 samples/line reconstructed to an image matrix of 256x256, scan time=18:55. In all scans, the same 36 slices, 3mm thick were prescribed. All DTI images were interpolated to cubic voxels (0.9375mm x 0.9375mm x 0.9375mm). The subjects were asked to remain in the same position throughout all 4 DTI acquisitions. In SE-EPI-DTI, eddy-current distortions were corrected by registering all DW images to the mean DW images, using a 6-parameter 2-D registration algorithm [4]. Distortions due to field-inhomogeneities were corrected in both SE-EPI-DTI datasets. A 3x3 low-pass filter was applied on all raw Turboprop-DTI images. Diffusion tensors, eigenvectors, eigenvalues, and fractional anisotropy (FA) values were estimated in each voxel. FA maps were compared to the high-resolution anatomical images to assess the amount of distortions. Seven fiber-bundles were traced in all datasets, using the FACT algorithm (fiber assignment by continuous tracking) (Table 1) [5]. For each fiber-tract, similar seed regions were selected in all DTI acquisitions. The percentage of voxels that were common in homologous tracts mapped using two different DTI datasets, was measured for all 7 fiber-bundles, for the following pairs of DTI acquisitions: Pair#1=(Turboprop-DTI & Turboprop-DTI), Pair#2=(Turboprop-DTI & SE-EPI-DTI$_{12}$), Pair#3=(Turboprop-DTI & SE-EPI-DTI$_{138}$).

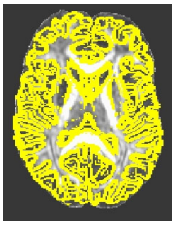

Figure 1: Borders between white matter, gray matter and CSF, produced from MPRAGE data, are well aligned with FA maps from Turboprop-DTI.

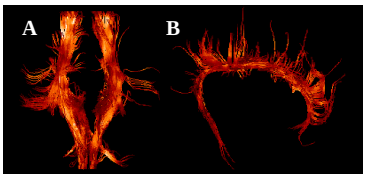

Figure 2: Fibers of the cortico-spinal tract (A) and the cingulum (B) mapped using Turboprop-DTI data.

Results: Comparison of Turboprop-DTI FA maps with high resolution anatomical scans showed no significant distortions (Fig.1). In contrast, in SE-EPI-DTI, residual distortions, as well as signal loss and pile-up were found in the frontal and temporal lobes, and in the region of the brainstem. Fiber-bundles produced from Turboprop-DTI data were undistorted and consistent with findings from anatomical studies (Fig.2). In SE-EPI-DTI, even after correction of susceptibility and eddy-current-related distortions, the tracts that were produced were often slightly distorted, or terminated early in the frontal and temporal lobes, and near the brainstem. In the rest of the analysis, fibers reconstructed from Turboprop-DTI data were considered as the reference fibers. The percentage of voxels that were common between maps of the same tracts produced from two separate DTI scans are listed in Table 1, for the selected fiber-bundles of a single subject. In all cases, the percentage of similarity was the highest when comparing the same fibers obtained with two separate Turboprop-DTI scans. Lower percentages were measured when comparing fibers produced from a Turboprop-DTI dataset and any of the two SE-EPI-DTI acquisitions (Table 1). Although all subjects were asked to remain in the same position for all DTI scans, the percentage of similarity for fibers mapped using two separate Turboprop-DTI datasets was not 100%, or even comparable to that. This was mostly due to noise causing the fiber-endings to vary from one acquisition to the other, and due to unavoidable subject motion. The percentages for pairs #2 and #3 were even lower than those for pair #1, mainly due to residual distortions and premature fiber termination when tracking using the SE-EPI-DTI datasets.

	Pair#1	Pair#2	Pair #3
Corpus callosum	85%	73%	73%
Cortico-spinal tract	81%	62%	64%
Superior longitudinal	78%	63%	62%
Uncinate fasciculus	68%	52%	52%
U-fibers of frontal lobe	78%	61%	67%
Fornix	73%	53%	60%
Cingulum	74%	53%	49%

Table 1. The percentage of voxels that are common between maps of the same tracts produced from two separate DTI scans.

Discussion: Knowledge of the exact location of a lesion with respect to eloquent white matter pathways is of great value to neurosurgeons in planning the appropriate surgical strategy. However, current DTI acquisitions using SE-EPI-DTI suffer from geometric distortions due to magnetic field inhomogeneities and eddy currents. Consequently fibers produced using this technique were shown to be distorted, and oftentimes, prematurely terminated. This severely limits the clinical potential of fiber-tracking methods. In contrast, Turboprop-DTI acquisitions provided undistorted white matter fiber-tracts, even near magnetic field inhomogeneities, in less than 19 minutes of total scan time, and without requiring additional scans or pre-processing. Therefore, Turboprop-DTI appears to be superior to SE-EPI-DTI for the purpose of acquiring DTI data for tractography applications.

References: [1] Basser PJ, et al., Magn Reson Med 2000;44:625-632. [2] Pipe JG, ISMRM 2002:p.435. [3] Hasan KM, et al., J Magn Reson Imag 13:769-780. [4] Woods RP, et al., J Comp Assist Tomogr 1998;22:144-154. [5] Mori S, et al., Ann Neurol 1999;45:265-269.