Reproducibility of Tractography Results: Turboprop-DTI vs. Spin-Echo Echo-Planar DTI

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Introduction: The accuracy and reproducibility of human white matter fiber-tracking results is of critical importance in the clinical setting as well as in studies of normal brain structure and development. Currently, DTI data for tractography [1] is commonly acquired with spin-echo echo-planar DTI (SE-EPI-DTI), or variations of it, which suffers from severe susceptibility and eddy current related artifacts. These may lead to distortion, premature termination, or even complete loss of fibers [2]. In contrast, Turboprop-DTI [3] is based on the multishot gradient and spin-echo sequence (GRASE), which is relatively immune to susceptibility and eddy-current related artifacts, thus producing tracts that are more consistent with the anatomy [2]. The goal of this study was to compare the reproducibility of fiber-tracking results based on SE-EPI-DTI and Turboprop-DTI datasets. The intra-session reproducibility of tractography results was similar for both Turboprop and EPI-based DTI data. However, the inter-session reproducibility was higher for Turboprop than EPI-based DTI data. Thus, Turboprop may be a more appropriate DTI data acquisition technique for longitudinal tractography studies.

Methods: All of the 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. High order shimming was applied for all the SE-EPI-DTI scans. Data from a dual-echo gradient-echo sequence (GRE) with TE$_1$=7ms, TE$_2$=18.4ms, TR=2000ms, scan time=4':24", were 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. Turboprop-DTI data were also acquired, with scan parameters: TR=5000ms, FOV= 24cm x 24cm, 16 blades, 8 spin-echoes per blade, 5 k-space lines acquired per spin-echo, 192 samples/line, reconstructed to an image matrix of 256x256, and scan time=18':55". In the first scan session, all subjects were asked to keep their head in the conventional position for head scanning (supine) and to maintain the same position throughout the examination. The SE-EPI-DTI$_{12}$, SE-EPI-DTI$_{138}$, and the Turboprop-DTI scans were performed twice. In the second scan session, the subject was asked to rotate her head around the inferior-superior axis of her body, by approximately 45° to the left relative to the supine position, and maintain the same position throughout the examination. All DTI scans were performed only once in this session. 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 all SE-EPI-DTI datasets. Diffusion tensors, eigenvectors, eigenvalues, and fractional anisotropy (FA) values were estimated in each voxel. Six fiber-bundles were traced in all datasets, using the FACT algorithm, the multi-ROI approach and similar seed regions (Table 1) [5]. The fiber-lines of each traced pathway were substituted with a 3D volumetric representation of the fiber-bundle. The ratio of the number of voxels that were common in homologous tracts mapped using two different DTI datasets divided by the total number of voxels included in at least one of the homologous pathways, was measured for all 6 fiber-bundles and for the pair of SE-EPI-DTI$_{12}$, the pair of SE-EPI-DTI$_{138}$ and the pair of Turboprop-DTI datasets from the first session (intra-session reproducibility). Similar ratios were estimated for pairs of datasets obtained with the same technique in two different sessions (inter-session reproducibility).

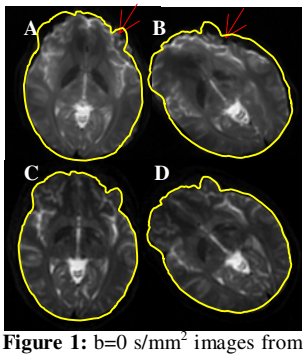

Figure 1: b=0 s/mm^2 images from SE-EPI-DTI$_{12}$ (A, B) and Turboprop-DTI (C, D) acquisitions. Images A and C were acquired during the first scan session. Images B and D were acquired on a different day. The outline of the brain, as determined by high-resolution anatomical 3D-MPRAGE data is overlaid on all images. Distortions are visible in the SE-EPI-DTI images (A, B). These distortions are dependent on head positioning (red arrows). No distortions are visible in the Turboprop-DTI images (C, D).

Results: Comparison of Turboprop-DTI images with high resolution anatomical scans showed no significant distortions, or artifacts (Fig.1). In contrast, SE-EPI-DTI data were characterized by residual distortions, as well as signal loss and pile-up in regions such as the brainstem, the frontal and temporal lobes (Fig.1).

The intra-session reproducibility for UF fibers was slightly higher when using Turboprop-DTI data, for FM and IFO fibers when using SE-EPI-DTI$_{12}$ data, and for the fornix, CST and ILF when using SE-EPI-DTI$_{138}$ data. However, the differences in intra-session reproducibilities were not significant. In contrast, the inter-session reproducibility of fiber tracking results was in general higher in Turboprop-DTI than SE-EPI-DTI$_{12}$, and SE-EPI-DTI$_{138}$ acquisitions (Table 1). Only for the CST the inter-session reproducibility was slightly higher when using SE-EPI-DTI$_{138}$ than Turboprop-DTI data.

	Turboprop-DTI	SE-EPI-DTI$_{12}$	SE-EPI-DTI$_{138}$
Fornix	54.48%	45.35%	29.62%
FM	60.94%	37.55%	46.63%
CST	57.58%	38.50%	63.70%
ILF	56.61%	40.77%	44.72%
IFO	46.25%	33.08%	48.22%
UF	52.66%	36.96%	48.13%

Table 1: Inter-session reproducibility for different fibers and acquisition techniques.

Discussion: Accurate and reproducible mapping of white matter fiber-tracts is of great importance for clinical applications of tractography and for research on normal brain structure and development. However, conventional SE-EPI-DTI acquisitions suffer from geometric distortions and artifacts due to magnetic field inhomogeneities. Consequently traced fibers can be distorted, and oftentimes, prematurely terminated. Moreover, susceptibility-related distortions and artifacts depend on head positioning. Thus, tractography results for fibers near magnetic susceptibility effects may vary between scanning sessions. This reduces the inter-session reproducibility of tracking results for SE-EPI-DTI. In contrast, white matter fiber-tracts produced from Turboprop-DTI data are unaffected by magnetic field inhomogeneities. Thus, the inter-session reproducibility of tractography results is higher for Turboprop-DTI than SE-EPI-DTI. For the same positioning of the head, intra-session reproducibility was slightly higher in SE-EPI-DTI than Turboprop-DTI. This was probably due to the higher signal to noise ratio (SNR) in the SE-EPI-DTI data.

In conclusion, fiber-pathways mapped using data obtained with Turboprop-DTI are more consistent with the anatomy and more reproducible between scanning sessions, than tracts produced using SE-EPI-DTI data. Therefore, Turboprop with sufficient (SNR) may be a more appropriate DTI data acquisition technique for several tractography applications.

References: [1] Basser PJ, et al., Magn Reson Med 2000;44:625-632. [2] Gui, M., et al., ISMRM. 2004: p. 1283. [3] Pipe JG. ISMRM 2002, p. 435 [4] Woods RP, et al., J Comp Assist Tomogr 1998;22:144-154. [5] Mori S, et al., Ann Neurol 1999;45:265-269.