Effects of Turboprop diffusion tensor imaging acquisition parameters on the noise of fractional anisotropy

A. A. Tamhane[1], and K. Arfanakis[1]
[1]Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, IL, United States

Introduction: Traditionally, DTI data is acquired with EPI because of its short imaging time. However, EPI-based DTI suffers from eddy-current and magnetic field inhomogeneity-related artifacts. Turboprop[1] is characterized by low sensitivity to eddy-current and B_0 effects, and is gaining popularity in DTI studies of the brain. In EPI-based DTI, it has been shown[2-4] that, measuring diffusion weighted (DW) signals in multiple diffusion directions instead of acquiring multiple copies of few DW images, reduces the noise in fractional anisotropy (FA). In addition, for anisotropic diffusion, using acquisition schemes with less than approximately 30 diffusion directions causes the noise in FA to be dependent on the orientation of the primary eigenvector of the tensor. Due to the k-space sampling pattern used in Turboprop, where the central region of k-space is sampled by all blades, while the periphery is sampled by fewer or even one blade, the concept of acquiring a "single" or "multiple" copies of a DW image is not well-defined. One can produce a single Turboprop image using, for example, 16 or 32 blades. Also, the echo-train length (ETL) and turbo-factor affect the number of lines in a blade, the number of blades required to cover k-space, the signal decay in a blade, as well as the amount of data collected, and thereby the noise in FA. Therefore, the goal of this study was to investigate the effect of the number of blades, ETL, turbo-factor, and number of diffusion directions on the noise of FA in Turboprop-DTI.

Methods: Turboprop-DTI acquisitions were simulated for a uniform disc-shaped object, covering most of the field of view and containing the same cylindrical tensor in each voxel. Two different FA values {0.5, 0.9}, different orientations of the simulated tensors (uniformly distributed in 3D space), and two encoding schemes with 6 (ICOSA6) and 30 (ME30) directions[3], were evaluated separately. In all cases, the diffusion weighting was b=1000 s/mm^2, the total number of DW images was equal to 6 times the number of b=0s/mm^2 images, and the scan time was 20 minutes for simulated acquisitions of 45 slices. In acquisitions with the ICOSA6 scheme different numbers of blades were considered: {15, 19, 25, 32}. Also, ETL values of: {4, 8, 12, 16} with a turbo-factor = 5, and turbo-factor values of: {3, 7, 11, 15} with an ETL = 6 were evaluated. Similarly, in acquisitions with the ME30 scheme, {3, 4, 5, 6} blades, ETL of {6, 8, 10, 12} with a turbo-factor = 5, and turbo-factor of {5, 7, 9, 11} with an ETL = 6, were tested. Turboprop k-space data were generated from the simulated b=0s/mm^2 and DW images. T_2 and T_2* decays were simulated for each blade, assuming T_2=90 ms and T_2*=50 ms throughout the phantom. Zero mean Gaussian noise was added to the real and imaginary components of the k-space data. Images were reconstructed from the noisy k-space data. Diffusion tensors and FA maps were produced. The standard deviation of FA (σ_{FA}) was measured in a selected region of interest (1000 voxels) in the middle of the phantom for all tensor orientations, FA values, and acquisition schemes. Furthermore, four Turboprop-DTI acquisitions were simulated from actual human brain DTI data. In these acquisitions the {number of blades, ETL, turbo-factor, diffusion encoding scheme} were set to I_1={15, 16, 5, ICOSA6}, I_2={34, 6, 3, ICOSA6}, M_1={3, 12, 5, ME30}, M_2={6, 6, 5, ME30}. T_2 and T_2* decays were simulated, and zero mean Gaussian noise was added in k-space. Tensors were estimated and σ_{FA} maps were produced for each acquisition scheme, from 1000 noisy datasets.

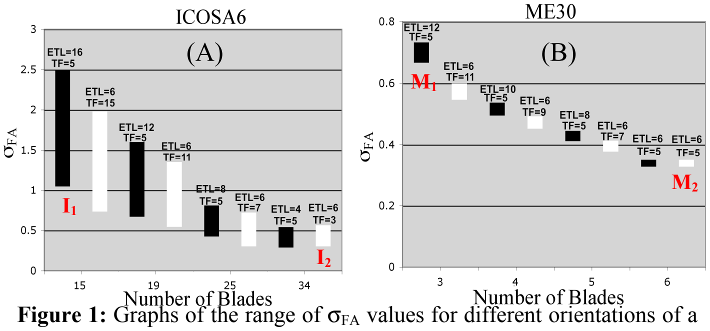

Figure 1: Graphs of the range of σ_{FA} values for different orientations of a diffusion tensor with FA=0.9, as a function of the number of blades, ETL, and turbo-factor, for (A) ICOSA6 and (B) ME30 encoding schemes with the same scan time. Black bars: turbo-factor = 5 and varying ETL; white bars: ETL = 6 and varying turbo-factor.

Results & Discussion: The Turboprop-DTI simulations with the uniform disc-shaped phantom revealed that increasing the number of diffusion directions, while maintaining the same scan time, reduces the range of σ_{FA} values for different orientations of the tensor (reduced height of the bars in Fig.1B compared to 1A). This finding is similar to what has been shown for SE-EPI-DTI[2-4]. Furthermore, in Turboprop-DTI, for a given number of diffusion directions and scan time, σ_{FA} decreases for an increasing number of blades, a lower ETL, and a lower turbo-factor (Fig.1). These findings are due to the fact that, when more blades are used, fewer lines are required in each blade in order to cover k-space. Therefore, for an increasing number of blades, a lower ETL and turbo-factor are required, limiting T_2 and T_2* decay at the center of k-space, and reducing the σ_{FA}. Additionally, in figure 1, there are two combinations of ETL and turbo-factor for any given number of blades. The acquisition schemes with higher turbo-factor (white bars) resulted in generally lower σ_{FA} than those with higher ETL (black bars) (Fig.1). This is due to the additional time required for 180° pulses, which allows additional T_2 decay to occur before the signals in the center of k-space are acquired. Similar observations were made when FA was equal to 0.5. All findings from the simulations on the uniform phantom were verified in the simulated Turboprop-DTI acquisitions in the human brain. Figure 2 demonstrates that the range of σ_{FA} values for different tensor orientations was lower when more diffusion directions were used (I_1 vs. M_1). Also, σ_{FA} decreased for an increasing number of blades, a lower ETL, and a lower turbo-factor (Fig.2, I_1 vs. I_2, M_1 vs. M_2). Hence, in Turboprop-DTI, just increasing the number of diffusion directions is not sufficient to optimize noise in FA. It is necessary to increase the number of blades, and decrease ETL and turbo-factor, while maintaining a) a high TR for sufficient T_1 recovery and for acquisition of the required number of slices, and b) a sufficient number of lines per blade for accurate motion correction[5].

	I_1	I_2	M_1	M_2
Genu	0.28	0.03	0.07	0.03
Splenium	0.15	0.03	0.05	0.03
Internal Capsule	0.12	0.03	0.06	0.03

Table 1: Average σ_{FA} values in white matter regions for acquisition schemes I_1, I_2, M_1 and M_2.

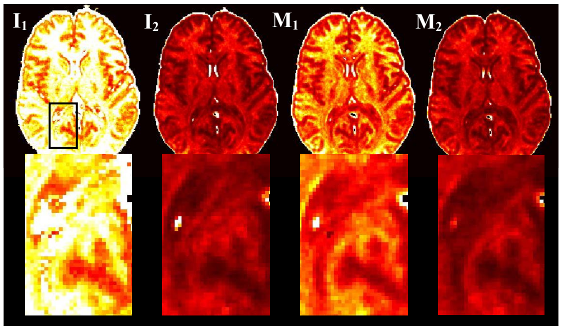

Figure 2: σ_{FA} maps for acquisition schemes I_1, I_2, M_1 and M_2. The rectangular region shown for I_1 was magnified for all schemes.

References: 1) Pipe JG, et al. Magn Reson Med 2006;55:380-5. 2) Jones DK, et al. Magn Reson Med 1999;42:515-25. 3) Hasan KM, et al. J Magn Reson 2001;13:769-780. 4) Jones DK, Magn Reson Med 2004;51:807-15. 5) Tamhane AA, et al. Magn Reson Med 2009;62:174-82.