Investigation of the Effects of Quality Weighting in Turboprop-DTI on the Diffusion Tensor Noise due to Brain Pulsation

M. Gui[1], Z. Hu[1], and K. Arfanakis[1]
[1]Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, IL, United States

Introduction: In the image reconstruction process for Turboprop diffusion tensor imaging (DTI), weights representing the quality of the data are estimated for each k-space blade (quality weighting, QW), and used during reconstruction to reduce the contribution of corrupted blades to the final image [1]. The QW of each blade is obtained by comparing the central disc of k-space sampled by all blades, to the mean k-space data in the same disc across all blades. This weighting procedure reduces artifacts due to: bulk motion, odd/even echo fluctuations, and other sources of k-space data variation between blades. In this work, the degree to which the QW also compensates for the increase in the total variance of the diffusion tensor (TVDT) due to cardiac-induced brain pulsation is investigated in both simulations and experiments on humans [2].

Methods: Simulations: Five copies of gated Turboprop-DTI data from the brain of a human subject were first acquired using an ECG trigger delay of 350ms [3], when brain pulsation is minimal. The averaged data were used to calculate the diffusion tensor in each voxel, and in combination with the averaged b=0sec/mm^2 data and the diffusion tensor model, were used to simulate one set of ideal DTI data with no contamination. The effects of brain pulsation were then simulated. A Gaussian-shaped function centered at the center of mass of the lateral ventricles was used to simulate the spatial distribution of percent signal reduction due to brain pulsation. The function was multiplied with different factors to simulate different levels of pulsation. In each voxel, the direction of simulated pulsation was defined by the axis connecting the center of the Gaussian-shaped function and the voxel under consideration. Ideal DW intensities were reduced by considering the value of the Gaussian-shaped function in each voxel, the diffusion direction, and the orientation of pulsation. One set of maximally contaminated data was created. K-space blades were produced from the datasets with zero and maximum contamination [4]. Non-gated Turboprop-DTI acquisitions were then simulated by combining k-space blades with zero or maximum contamination, based on the timing of data collection and a simulated cardiac waveform. Gated Turboprop-DTI datasets were simulated by combining only blades with no contamination. Gaussian noise was added in k-space, and an ensemble of 800 noisy Turboprop-DTI datasets were produced. The same simulation was repeated for four different levels of brain pulsation, with maximum percent DW signal reduction ranging from 6% to 21%. The TVDT was estimated and compared between gated and non-gated data, as well as between gated or non-gated data reconstructed with and without QW, for all four levels of simulated brain pulsation.

Experiments: Cardiac-gated and non-gated Turboprop-DTI acquisitions were performed on 4 healthy subjects. Cardiac gating was achieved with an ECG trigger delay of 350ms. Data were reconstructed with and without QW for both gated and non-gated cases. All scans were repeated 5 times, and 800 bootstrap samples were created. The TVDT was then calculated in all voxels and all experiments. The TVDT was compared between gated and non-gated datasets, reconstructed with and without QW.

Maximum % signal reduction due to simulated pulsation	% Reduction in TVDT with gating	% Reduction in TVDT with QW in non-gated data
21%	37.6%	11.4%
16%	19.8%	8.9%
11%	9.5%	0.7%
6%	7.9%	-6.2%

Table 1. *Simulations.* Percent reduction in TVDT in the genu of the corpus callosum with gating, and with QW on non-gated data, for different levels of pulsation.

	% Reduction in TVDT with gating	% Reduction in TVDT with QW in gated data	% Reduction in TVDT with QW in non-gated data
Subj 1	11.5%	0.5%	3%
Subj 2	29.3%	0.9%	18.7%
Subj 3	46.5%	5.5%	5.3%
Subj 4	61.1%	0.2%	5.5%

Table 2. *Experiments on humans.* Percent reduction in TVDT of the genu with gating, and with QW in gated and non-gated Turboprop-DTI data.

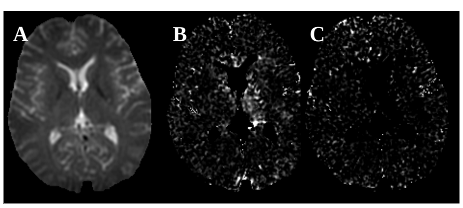

Figure 1: A) b=0sec/mm^2 image from a non-gated Turboprop-DTI dataset on a human subject. Map of the B) decrease and C) increase in TVDT when using QW vs. when not using QW during reconstruction.

Results and Discussion: The simulations and experiments on humans demonstrated that, the TVDT in regions known to be affected by brain pulsation was significantly reduced in cardiac-gated compared to non-gated Turboprop-DTI acquisitions (Tables 1, 2). Thus, cardiac-induced brain pulsation increases the noise in the diffusion tensor in Turboprop-DTI. In the simulations, the percent reduction in TVDT when using QW in non-gated data decreased when the amount of simulated pulsation was reduced, and TVDT even increased when using QW with very low levels of brain pulsation (Table 1). This is explained as follows. In the simulations, brain pulsation and added noise are the only factors that contribute to the TVDT. Also, QW assigns to each blade one weight that accounts for all factors that reduce the quality of the data in that blade. When the contribution of brain pulsation to the TVDT is more significant than that of added noise, QW reduces the importance of blades corrupted by pulsation in the final reconstruction, compared to less corrupted blades, and thereby the TVDT is reduced. However, when the brain pulsation contributes less to TVDT than added noise, different blades are assigned different weights during QW even though they contain the same amount of added noise, thus increasing TVDT. In the experiments on human subjects, in addition to system noise and brain pulsation, there are other factors that contribute to the TVDT, such as bulk motion, odd/even echo variations etc. In cardiac-gated data, the TVDT was not significantly reduced when using QW, suggesting that there was only minor brain pulsation and bulk motion (except for subject 3) (Table 2). In non-gated data, TVDT was reduced when using QW, suggesting that, if the bulk motion was similar in the gated and non-gated data from the same subjects, QW reduced the effect of brain pulsation on the TVDT. Comparison of TVDT maps from non-gated datasets between reconstructions with and without QW also demonstrated reduced TVDT when using QW, especially near the ventricles (Fig.1), suggesting that QW reduced the effects of cardiac-induced brain pulsation on the TVDT. However, in the simulations, as well as in the experiments on humans, the reduction in TVDT in non-gated datasets when using QW was not as high as the reduction in TVDT achieved with cardiac-gating (Tables 1, 2).

In conclusion, the degree to which QW reduces the effects of brain pulsation on the TVDT depends on how significant brain pulsation is compared to other effects that corrupt the data in a blade, such as bulk motion, odd-even echo variations etc. When data are corrupted significantly by other factors than brain pulsation then QW is unable to correct the effects of pulsation on the TVDT. Finally, the QW is not as effective as cardiac-gating in reducing the effects of brain pulsation on the TVDT.

References: [1] Pipe JG, et al., MRM 2006;55:380-5. [2] Wirestam R, et al., JMRI 1996;6:348-55. [3] Pierpaoli C, et al., ISMRM 2003:p.70. [4] Tamhane AA, et al ISMRM 2007;p.7.