Contribution of Cardiac-Induced Brain Pulsation to the Noise of the Diffusion Tensor in Turboprop-DTI

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Introduction: Turboprop-DTI[1] is rapidly attracting attention due to its greatly reduced sensitivity to motion and magnetic-field inhomogeneities. The central disc of k-space sampled by all blades in Turboprop-DTI can be used as a 2D navigator, and allows reduction of artifacts caused by bulk motion. However, in addition to bulk motion, incoherent cardiac-induced brain pulsation leads to intravoxel phase dispersion[2] and signal loss in diffusion-weighted images. In this work, the effects of cardiac-related brain pulsation on the diffusion tensor calculation in Turboprop-DTI were assessed both in simulations and experiments. The effects of cardiac-related brain pulsation were also investigated for different Turboprop-DTI acquisition schemes and image reconstruction procedures.

Methods: Experiment: Turboprop-DTI scans on 9 healthy subjects were performed on a 3T GE MRI scanner, using: ETL=8, Turbofactor=5, 128 samples per line, 6 diffusion directions, b=900 sec/mm^2. One slice through the genu of the corpus callosum (GCC) was prescribed. Two acquisition schemes were used: (I) 5 blades with 2 repetitions, and (II) 10 blades with 1 repetition. Each scheme was applied on 3 subjects with both cardiac-gated and non-gated Turboprop-DTI. Cardiac gating was achieved with a peripheral pulse trigger delay of 100ms, when cardiac-induced brain pulsations are negligible (diastolic period of the heart cycle). Three other subjects were scanned with both Turboprop-DTI schemes and diastolic gating. All scans were repeated 4 times, and 800 bootstrap samples were created. The total variance of the diffusion tensor (TVDT) was then calculated in all voxels and all experiments. The TVDT was compared between gated and non-gated datasets, as well as between the two acquisition schemes.

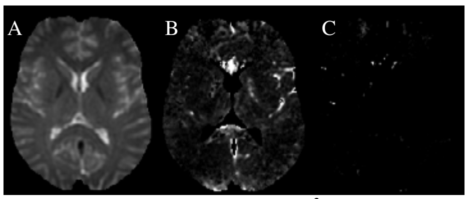

Figure 1. A) Simulated b=0sec/mm^2 image. B) Map of the increase in TVDT when using simulated non-gated versus gated Turboprop-DTI data. C) Map of the increase in TVDT when using simulated gated versus non-gated Turboprop-DTI data. Ten blades were used in this simulation.

Simulations: For the purposes of the simulations, actual Turboprop-DTI data were first acquired on a subject using electrocardiographic (ECG) trigger delay[3] of 300 ms and 120ms, to produce images with minimum and maximum contamination from cardiac pulsations, respectively. After extensive interpolation, appropriate rotation of the data in image space, and 2D FFT, k-space blades in different orientations were produced from the raw images with minimum and maximum contamination. Non-gated Turboprop-DTI acquisitions were then simulated by combining k-space blades with minimum 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 minimum contamination. Gaussian noise was added in k-space 800 times and raw Turboprop-DTI images were reconstructed. Gated and non-gated Turboprop-DTI acquisitions with 5, 10, 15 and 20 blades, were simulated. Additionally, a "quality" weight was calculated for each blade during image reconstruction, by comparing the central disc of the blade with the mean of the disc from all blades[4]. "Low-quality" samples were weighted less than "high-quality" samples during reconstruction. Images were reconstructed with and without this "quality" weighting procedure for schemes I and II. The TVDT was calculated in all cases and compared between gated and non-gated acquisitions, between sampling patterns with different number of blades, as well as for image reconstruction with and without quality weighting.

Scheme I (5 blades, 2 reps)	% Reduction in TVDT	Scheme II (10blades, 1rep)	% Reduction in TVDT	Scheme I vs. II	% Reduction in TVDT
Subject 1	18.1%	Subject 4	27.1%	Subject 7	16.7%
Subject 2	31.7%	Subject 5	47.4%	Subject 8	23.7%
Subject 3	89.5%	Subject 6	76.7%	Subject 9	23.8%

Table 1. *Experiments on humans.* Percent reduction in TVDT of the GCC in gated vs. non-gated Turboprop-DTI data acquisitions with schemes I (left) and II (middle). (Right) Percent reduction in TVDT of the GCC when using diastolic gating and scheme I instead of scheme II.

Acquisition Scheme	TVDT	Absolute ΔTVDT	% Reduction in TVDT
(II) with qual weight	414	195	47.1%
(II) no qual weight	401	198	49.4%
(I) with qual weight	383	196	51.1%
(I) no qual weight	380	189	49.7%

Table 2. TVDT of the GCC, absolute and percent reduction in TVDT when using gating, for simulated acquisitions with schemes I and II, with and without quality weighting. TVDT and ΔTVDT values are in 10^{-10}mm^4/sec^2.

# of blades	Absolute ΔTVDT	% Reduction in TVDT
5	392	47.1%
10	198	49.4%
15	128	48.1%
20	89	45.0%

Table 3. Absolute and percent reduction in TVDT of the GCC when using gating for simulated acquisitions with different numbers of blades. ΔTVDT values are in 10^{-10}mm^4/sec^2.

Results and Discussion: The TVDT of the GCC was significantly reduced in cardiac-gated compared to non-gated Turboprop-DTI acquisitions (Table 1). Comparison of TVDT maps between simulated gated and non-gated Turboprop-DTI acquisitions demonstrated higher TVDT in the non-gated datasets, especially near the ventricles (Fig.1). These results suggest that cardiac-related pulsations significantly increase noise in the elements of the diffusion tensor in Turboprop-DTI. Furthermore, the TVDT of the GCC was lower for scheme I than scheme II, in the experiments on humans (Table 1) as well as in the simulations (Table 2, TVDT column). This was primarily due to the fact that in acquisitions with more repetitions, averaging occurred in image space using magnitude data. For increasing number of blades and increasing imaging time, the absolute reduction in TVDT of the GCC when using gating decreased, while the percent reduction in TVDT of the GCC remained constant at ~50% (Table 3). This finding suggests that although increasing the number of blades collected reduces the absolute difference in TVDT between gated and non-gated acquisitions, the effects of cardiac pulsations are not eliminated, and gating can reduce the TVDT by approximately the same percentage for any number of blades used. Finally, quality weighting did not affect the TVDT (Table 2), indicating that the quality weighting procedure cannot identify blades that have been corrupted by cardiac-related brain pulsations.

In conclusion, cardiac-induced brain pulsations increase the noise in the elements of the diffusion tensor in Turboprop-DTI, similar to what has been reported for other DTI sequences[3]. Since the quality weighting procedure included in the conventional Turboprop reconstruction technique[4] cannot identify and eliminate contaminated blades, cardiac gating is required in order to reduce the effects of brain pulsations.

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] Pipe JG, et al., MRM 2002;47:42-52.