A scanner stability test for Diffusion Tensor Imaging

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Introduction: Diffusion tensor imaging (DTI) provides information on macroscopic patterns in the tensor field; DTI signal is affected by microscopic changes and the method is extremely sensitive to tissue microstructure that is not observed in routine MRI. Small signal changes and instabilities can significantly and adversely affect DTI metrics and fiber tracking. As a result, conventional quality assurance (QA) schemes cannot be applied to DTI; there is no robust set of QA tests that are suitable for DTI. Weisskoff observed that while normally tracked performance measures such as SNR and uniformity are consistent between scanners and over time, the intensity fluctuations between images for an fMRI time series can vary by an order of magnitude (1). Such intensity fluctuations are also observed in DTI, resulting from instabilities in the RF or gradient amplifier, center frequency, or shim. We propose a scanner stability test for DTI that is adapted from an fMRI scanner stability test (1). The test can be easily performed on any clinical scanner, without the need for complicated data analysis. We report on stability measures using copper sulphate ($CuSO_4$) and mineral oil phantoms that were imaged with an 8-channel SENSE head coil. We also compare results from 1.5 T and 3T scanners.

Theory: For a region-of-interest (ROI) linearly increasing from 1 pixel to a circular ROI with a diameter of n pixels, the standard deviation over a time series scan would decrease as the square root of 1/n. However, dynamic system instability can lead to signal amplitude fluctuations, resulting in a larger standard deviation. For a DTI series of N gradient cycles, the relative SNR fluctuation in a ROI, *n* pixels in diameter, can be defined as $F_n = \frac{\sqrt{\frac{1}{N-1}\sum_i (m_i^n - \overline{m}^n)^2}}{\overline{m}^n}$. $F_{n,t} = \frac{1}{n \cdot SNR}$ is the theoretical achievable relative fluctuation in the absence of instabilites. The measured fluctuations can be compared with theoretical achievable values to characterize scanner instabilities for a DTI series. The ratio $\frac{F_n}{F_{n,t}}$ is a quantitative measure that describes instabilities arising from a particular hardware configuration and for a particular set of scan parameters such as the ROI size.

Methods: Clinical DTI scans were run on either a $CuSO_4$ phantom or an oil phantom, and imaged on 1.5 T and 3 T MR scanners (Achieva, Philips Medical Systems, Best, The Netherlands) with triple axis gradients (40 G/cm max) using an 8-channel SENSE head coil in receive mode. The scans were run with both a 30 direction gradient acquisition scheme [2] and a single arbitrarily chosen gradient direction scheme repeated 30 times. Other image acquisition parameters are as follows: single-shot echo planar imaging (EPI) scan with TE = 103 ms, TR = 3650 ms, b = 700, SENSE factor = 2, isotropic resolution = 2mm, one signal average. Three slices were analyzed; SNR was measured for each image in the DTI series. Fluctuations were calculated from the mean peak-to-peak variations in SNR. The relative deviation of the DTI series was then plotted versus ROI size. All data were analyzed in IDL with a modified version of the stab.pro routine found at http://godzilla.kennedykrieger.org/.

Results and Discussion: The results are summarized as follows:

Relative % fluctuation	**1.5 T**		**3 T**	
Mineral oil (TR = 3650 ms)	1 direction	30 directions	1 direction	30 directions
	0.53 ± 0.03	0.55 ± 0.02	0.49 ± 0.06	0.50 ± 0.02

Table 1: Measured % signal fluctuations for a DTI scan series as a function of field strength.

For the mineral oil phantom and a single gradient direction repeated 30 times, we found that the instabilities were similar to those of a gradient scheme with 30 varying directions, regardless of field strength. This clearly demonstrates that a varying-direction gradient scheme is not additional source of instability in DTI metrics. The 1.5 T scanner exhibited similar dynamic instability as the 3 T, suggesting that overall SNR did not play a major role in the instabilities measures for the clinical DTI scan.

Relative % fluctuation	**1.5 T** (TR = 897 ms)		**3 T** (TR = 1140 ms)	
	1 direction	30 directions	1 direction	30 directions
Copper sulphate	0.22 ± 0.07	1.31 ± 0.08	0.07 ± 0.01	2.65 ± 0.07
Mineral oil	0.20 ± 0.03	0.55 ± 0.31	0.07 ± 0.01	0.23 ± 0.06

Table 2: Measured % signal fluctuations for a DTI scan series as a function of the phantom composition.

The mineral oil phantom resulted in less fluctuation than the $CuSO_4$ phantom for all the cases shown in Table 2 with the exception of the 1 direction scheme at 3T, probably attributable to the shorter T_2 and the higher fluidic mobility of $CuSO_4$. An immobile phantom is more appropriate for such a stability test. Furthermore, a shorter TR results in a large difference in the comparative instability measures between the 1 direction and the 30 direction gradient schemes. It is not clear as to why the 30 direction gradient scheme on the 3 T is far more unstable than on the 1.5 T. It is important to note that while we have performed stability tests for quadrature head coils, here we report on SENSE head coils. In the case of SENSE coils, the unfolding errors in the reconstruction algorithm should be considerably lower than the measured fluctuations.

Conclusion and Future Studies: DTI series fluctuations were compared with theoretically achievable values. The additional noise in the system from DTI series instability was thus characterized. This informs us on RF, gradient, shim, center frequency and other instabilities that cannot be characterized by routine MRI scanner performance tests but have an important role in scan performance and data validity. We found that a varying-direction gradient scheme is not a major source of instability in a DTI series. In the future we will explore and formulate the minimum tolerable fluctuation as a function of ROI size and SNR and for a given gradient direction scheme. We will also explore other phantoms that may be better suited for such a stability analysis, such as an immobile gel phantom with similar T_2 as white matter.

Reference:

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[2] Jones DK, Horsfield MA, Simmons A. Optimal strategies for measuring diffusion in anisotropic systems by magnetic resonance imaging. Magn Reson Med 1999;42:515–525.

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