Rapid Data Acquisition and Post-processing for Diffusional Kurtosis Imaging

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Introduction

Diffusional kurtosis imaging (DKI) is an extension of diffusion tensor imaging (DTI) that enables the estimation of diffusion metrics associated with diffusional non-Gaussianity [1-3]. These DKI-derived metrics are complementary to conventional DTI measures, such as the mean diffusivity (MD) and fractional anisotropy (FA), and allow for a more complete characterization of tissue microstructure. In particular, from a DKI dataset the mean kurtosis (MK) for the diffusion displacement probability distribution can be determined, which is potentially useful for quantifying brain tissue changes due to neuropathologies including Alzheimer's disease [4], schizophrenia [5], and attention deficit and hyperactivity disorder [6]. DKI, unlike DTI, is also capable of resolving white matter fiber crossings [7]. Established DKI acquisition protocols typically require 10 to 20 min for full brain coverage, and an additional time for post-processing of approximately an hour [2]. Here a more efficient DKI scheme is proposed that substantially reduces both the acquisition and post-processing times, making DKI more suitable for clinical studies.

Theory

The diffusional kurtosis is related to the diffusion-weighted signal intensity by: $\ln[S(b)] = \ln[S(0)] - bD + b^2D^2K/6 + O(b^3)$, (1)

where $S(b)$ is the signal intensity as a function of the b-value, D is the diffusion coefficient, and K is the diffusional kurtosis [1]. If S is measured for three different b-values (b_1, b_2, and b_3) and the $O(b^3)$ terms are neglected, then one may obtain D and K from

$$D = \frac{(b_3 + b_1)D^{(12)} - (b_2 + b_1)D^{(13)}}{b_3 - b_2}; \qquad K = 6\frac{D^{(12)} - D^{(13)}}{(b_3 - b_2)D^2}, \tag{2}$$

with $D^{(ij)} \equiv \ln[S(b_i)/S(b_j)]/(b_j - b_i)$. By utilizing Eq. (2) to calculate D and K, nonlinear fitting routines, which consume most of the post-processing time for prior methods, may be entirely avoided.

Methods

On a 3T Trio MR system (Siemens), diffusion-weighted images were acquired for a healthy volunteer using 30 gradient directions, six b values (b = 0, 500, 1000, 1500, 2000, and 2500 s/mm^2), and a twice-refocused-spin-echo echo planar imaging sequence. The b = 0 acquisition was repeated 9 times and averaged to reduce the effect of noise. The other imaging parameters were: voxel size = 3×3×3 mm^3, field of view = 222×222 mm^2, echo time = 100 ms, and repetition time = 5300 ms. The number of slices was 40 with a zero interslice gap, resulting in essentially full brain coverage. Parametric maps for the MD, FA, and MK were generated with in-house Matlab code both by using the full set of images with the previously described method based on nonlinear fits [2] and by using only the b = 0, 1000, and 2000 s/mm^2 images together with Eq. (2). In addition, MD and FA maps were generated from just the b = 0 and 1000 s/mm^2 images following a conventional DTI approach.

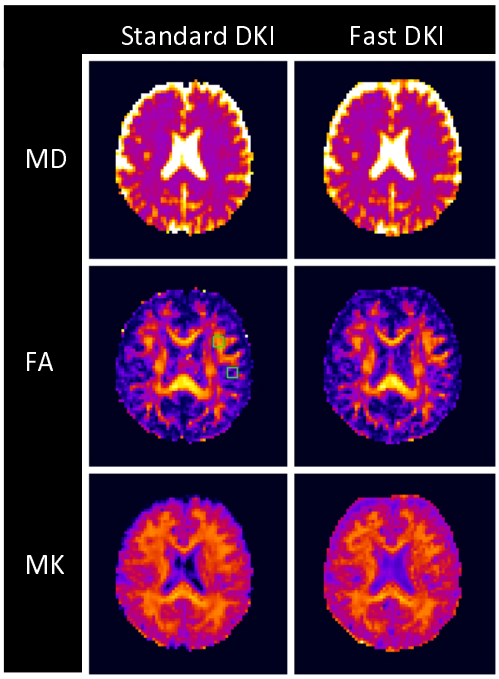

Figure 1. Parametric maps derived with the standard and fast DKI procedures. The maps are similar, but fast DKI has much shorter acquisition and post-processing times. The green squares show white matter (upper) and gray matter (lower) regions of interest used for Fig. 2.

Results

The total time to acquire the full set of images was 15 min 12 s with an associated post-processing time using the nonlinear fit approach of 48 min ("standard DKI"). The acquisition time for just the b = 0, 1000, and 2000 s/mm^2 images was 6 min 57 s with an associated post-processing time using Eq. (2) of 3 min ("fast DKI"). The acquisition time for just the b = 0 and 1000 s/mm^2 images was 4 min 12 s with an associated post-processing time of 2 min ("standard DTI"). Figure 1 shows that the quality of the parametric maps is similar for both standard and fast DKI. Figure 2 shows the mean MD, FA, and MK values in gray matter (GM) and white matter (WM) regions of interest, indicating that standard and fast DKI give nearly identical results. Also plotted are the MD and FA obtained with DTI; the FA is close to the DKI-derived values, but the MD is lower reflecting that DTI neglects the $O(b^2)$ term in Eq. (1).

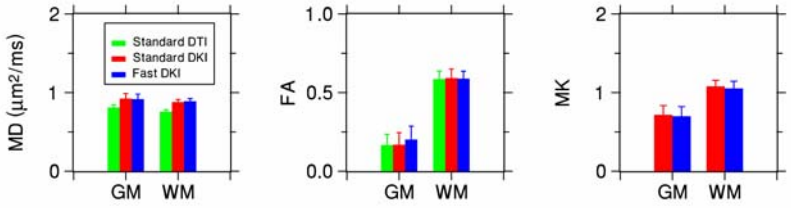

Figure 2. Mean values for diffusion metrics in GM and WM regions obtained with standard DTI, standard DKI, and fast DKI. The MK is not measurable with DTI.

Discussion

By acquiring an optimized dataset and using a more efficient post-processing algorithm, the fast DKI approach reduces the image acquisition time by over a factor of 2 and the post-processing time by a factor of 16 compared to the standard approach, while maintaining similar image quality. Replacing a standard DTI protocol with a fast DKI protocol adds less than 3 min to the image acquisition time and allows one to calculate all the conventional DTI metrics plus additional metrics of diffusional non-Gaussianity. DKI may thus be reasonably incorporated into many clinical protocols currently using DTI. In addition, the post-processing time for fast DKI is comparable to that for DTI, and with the use of a high performance programming language (e.g., C++), real-time generation of DKI maps should be possible.

References **1.** Jensen JH, et al. MRM 2005;53:1432. **2.** Lu H, et al. NMR Biomed 2006;19:236. **3.** Hui ES, et al. Neuroimage 2008;42:122. **4.** Lu H, et al. ISMRM 2006;14:723. **5.** Ramani A, et al. ISMRM 2007;15:648. **6.** Helpern JA, et al. ISMRM 2007;15:1580. **7.** Lazar M, et al. MRM 2008;60:774.