Diffusion Kurtosis Imaging (DKI) of In Vivo Human Brain at 7 T

E. E. Sigmund[1], C. Hu[1], M. Lazar[1], M. F. Falangola[1], J. H. Jensen[1], and J. A. Helpern[1]
[1]Radiology, New York University, New York, NY, United States

Background

Diffusion contrast plays a vital role in characterizing microstructure in the brain. The widely applied diffusion tensor imaging (DTI) (1) technique and its quantitative indices mean diffusivity (MD) and fractional anisotropy (FA) can probe the unidirectional anisotropy in most axonal white matter bundles. However, the model is insufficient to describe regions of fiber-crossing (2), and indices of anisotropy (FA) have limited value in macroscopically isotropic tissue (gray matter). A higher-order protocol termed diffusion kurtosis imaging (DKI) (3,4) has been previously demonstrated to overcome these limitations through the quantification of non-Gaussian diffusion. DKI provides quantitative white matter / gray matter contrast as well as a means to describe fiber-crossings. The present work describes the first implementation of DKI in vivo in a 7 T full body MRI scanner. The higher signal-to-noise ratio (SNR) in this platform potentially offers dramatically higher sensitivity and/or resolution, if the acquisition pulse sequence and protocol can be appropriately optimized.

Methods

A healthy volunteer brain scan was performed in a Siemens 7 T full body scanner using a 24-channel head coil (Nova Biomedical) and a double-echo, bipolar diffusion gradient, echo-planar imaging sequence. Imaging parameters were as follows : 128 x 128 matrix, 5 slices, 2 x 2 x 4 mm resolution, parallel imaging (GRAPPA) factor R=3 w/24 reference lines, 6/8 partial fourier, 2 averages, TR / TE = 1500 / 115 ms. Diffusion weighting : b = 0,500,1000,1500,2000,2500 s/mm^2, 30 directions. All slices were registered to the unweighted (b0) image; a 2-voxel median filter was applied. The signal decays (ln(M)) were fit to a second-order polynomial in the b-value (see Figure 1 for an example fit), where for each direction the linear term estimates apparent diffusion coefficient (ADC), and the quadratic term estimates apparent kurtosis coefficient (AKC). The ADC maps were processed to provide standard DTI maps (MD, FA, directivity), while the AKC maps were averaged to generated mean kurtosis (MK) maps. Histograms were evaluated for MD, FA, and MK.

Results

Figure 1 shows image results from the DKI acquisition at 7 T. The DTI maps show the expected contrast: comparable MD in white matter and gray matter, elevated FA in white matter and negligible FA in gray matter, and a direction-encoded colormap showing the local orientation of axonal white matter bundles (corpus callosum (red), corona radiate (blue), etc.). The MK map is nonzero throughout the brain and shows elevated values in white matter compared to gray matter . Histograms of the slice in Figure 1 are shown in Figure 2. The DTI indices MD and FA show well-known behavior: a single peak in the MD histogram, a low-FA peak for gray matter and a distributed tail for white matter. The MK histogram is more complex, showing two distinct peaks corresponding to gray matter (0.5-0.9) and white matter (1-1.4).

Discussion

These preliminary results are consistent with previous DKI studies at lower field (3 T) and confirm that comparable information is attainable at 7 T. As with numerous other reports(5-8), significant parallel imaging was required to minimize EPI image distortions at this field, which limited SNR and resolution to be comparable to those used at 3 T. Future optimization of this and other sequences should allow the high field SNR benefit to be realized for DKI.

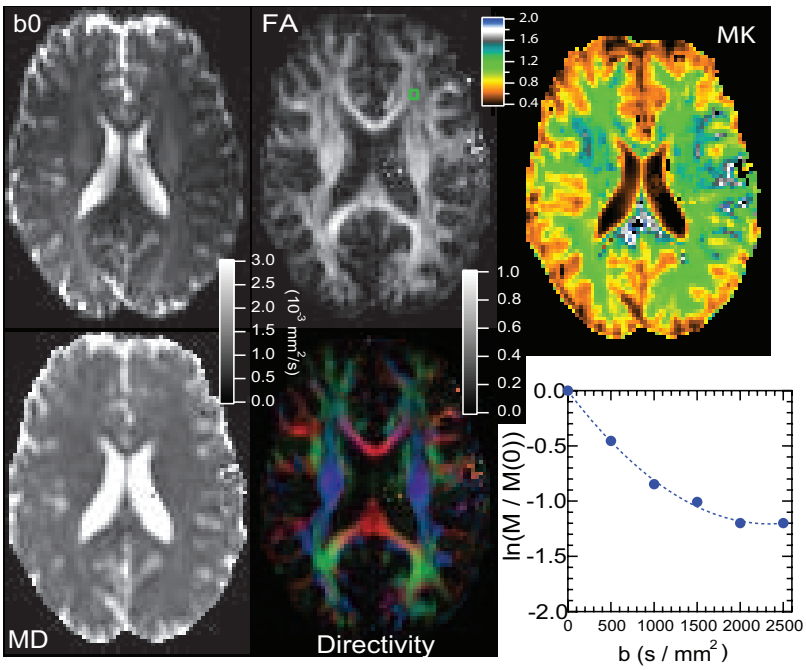

Figure 1: Diffusion kurtosis imaging (DKI) results at 7 T. Unweighted (b0) image, mean diffusivity (MD), fractional anisotropy (FA), color-coded directivity, and mean kurtosis (MK) maps are shown. Lower right : example magnetization decay for the region highlighted in the FA map and direction [0.7,-0.7,0.2].

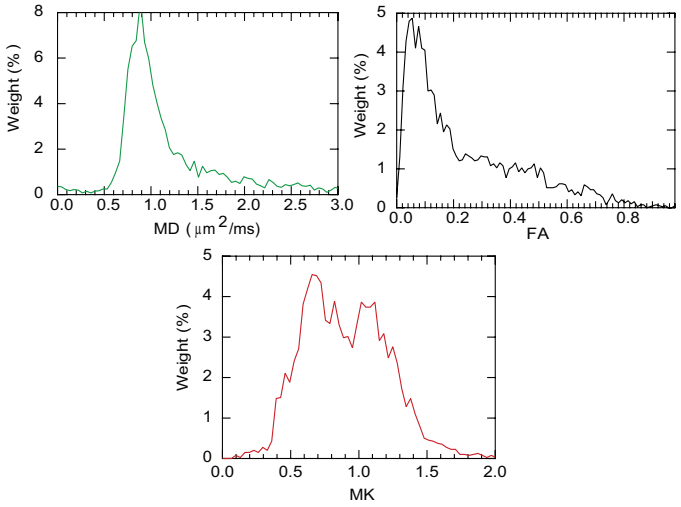

Figure 2: Single slice histograms of DKI indices at 7 T shown in Figure 1. Mean diffusivity (MD), fractional anisotropy (FA), and mean kurtosis (MK) maps are shown. The MD distribution is unimodal. the FA distribution shows a low gray matter peak and a broad white matter tail, and the MK shows distinct peaks for gray matter and white matter.

References

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