CSF Partial Volume Effect for Diffusional Kurtosis Imaging

C. Hu[1], J. H. Jensen[1], M. F. Falangola[1], and J. A. Helpern[1]

[1]Radiology, New York University School of Medicine, Center for Biomedical Imaging, New York, NY, United States

INTRODUCTION: Diffusion tensor imaging (DTI) has been widely used to study the diffusion properties of water in human brain. From DTI, the fractional anisotropy (FA) and the mean diffusivity (MD) can be calculated providing valuable information on the physical state of the brain tissue. One problem in the quantification of FA and MD, however, is the well-known cerebral spinal fluid (CSF) partial volume effect. Prior studies have shown how to assess this quantitatively by comparing results from conventional DTI with those from fluid-attenuated inversion recovery (FLAIR) DTI (1-3). Recently, our laboratory has developed a generalization of DTI called diffusional kurtosis imaging (DKI), which quantifies the nongaussianity of the diffusion process resulting from tissue microstructure diffusion barriers, such as cell membranes (4-6). From a DKI dataset, we can obtain all diffusion metrics used to characterize the micro-architectural complexity of brain tissue including MD and FA, along with a new metric called mean kurtosis (MK). In the present study, we present quantitative measurements of FA, MD, and MK in human brain with and without FLAIR.

METHODS: The experiments were conducted on a 3T MR system (Trio, Siemens Medical Solutions). DKI scans were performed on four healthy volunteers ranging from age 22 to 51 years. Both DKI experiments with and without FLAIR were performed using a twice-refocused-spin-echo (TRSE) diffusion sequence, to reduce eddy currents. A total of thirty different diffusion encoding directions were employed, and for each direction, six *b*-values (b = 0, 500, 1000, 1500, 2000, 2500 s/mm^2) were used. Other imaging parameters were: FOV = 256 × 256mm^2, acquisition matrix = 128 × 128, parallel imaging factor of 2 with 24 k-lines used as references, number of averages = 2, 15 AC-PC aligned slices to cover the frontal regions and temporal regions, slice thickness = 4 mm with interslice gap = 1 mm, voxel size = 2 × 2 × 4 mm^3, TR/TI/TE=6800/2300/108 ms for FLAIR-DKI, and TR/TE=2000/108 for normal DKI. The scan durations are 35 min for FLAIR-DKI and 12 min for normal DKI. The diffusion tensor and diffusional kurtosis tensor were computed using a previously described model (5), and parametric maps were calculated for FA, MD and MK. One slice above ventricles with the same anatomical structure from each of the 4 subjects was chosen for comparison, with fractional error maps being calculated from

$$\text{fractional error} \equiv \frac{\left| X_{FLAIR} - X_{Conventional} \right|}{X_{FLAIR}}, \qquad [1]$$

where X represents the MK, FA, or MD. From the same slice, white matter and gray matter were segmented using FA maps with the threshold 0.15, as has been used previously (1). In addition, regions of interest (ROIs) were drawn manually from 2 slices for the genu and splenium of the corpus callosum.

RESULTS and DISCUSSION: Figure 1 shows the fractional error maps of the MK, FA and MD (left to right) from a representative subject. The calibration bar gives the fractional errors as calculated from Eq. [1]. The MK fractional error map shows little change in MK, while the FA and MD values change much more significantly. This demonstrates that compared with FA and MD, MK is relatively insensitive to the partial volume effects of CSF.

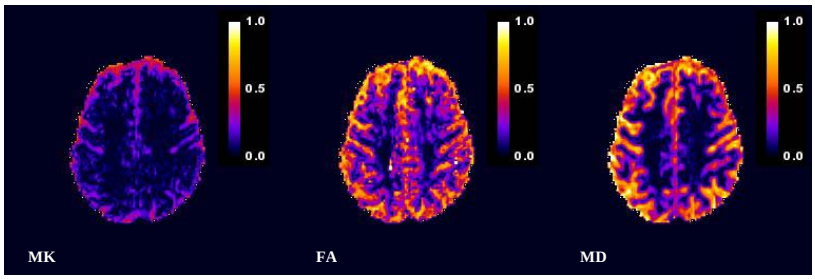

Figure 1: MK, FA, MD fractional error maps from a representative subject

Table 1 and Table 2 show the quantitative MK, FA, and MD value changes in corpus callosum and in cortical gray and white matter. Mean values were calculated from ROIs collected from all four subjects. Table 1 shows the average MK, FA and MD values with standard deviations for white matter and gray matter segmented using FA value of 0.15. FA changes about 13 percent in cortical white matter and 60 percent in gray matter, while MD changes around 4 percent in white matter and 30 percent in gray matter. From the same dataset and same ROIs, MK shows almost no change in white matter and only around 7 percent in gray matter. In genu and splenium of the corpus callosum the FA and MD changes are about twice as big as the changes from MK values (Table 2).

Table 1: MK, FA, MD values of white matter and gray matter with/without FLAIR

	WM			GM		
	MK	FA	MD	MK	FA	MD
no IR	1.001±0.026	0.32±0.02	0.92±0.05	0.70±0.02	0.08±0.01	1.56±0.14
IR	1.005±0.034	0.36±0.03	0.88±0.07	0.75±0.01	0.12±0.01	1.07±0.07
IR-no IR	**0.004**	**0.04**	**-0.03**	**0.05**	**0.04**	**-0.49**
percentage	**0.4%**	**13.0%**	**-3.6%**	**7.6%**	**59.5%**	**-31.3%**

Table2: MK, FA, MD values of genu and splenium CC with/without FLAIR

	CCg			CCs		
	MK	FA	MD	MK	FA	MD
no IR	1.16±0.09	0.73±0.05	1.07±0.11	1.20±0.04	0.81±0.03	1.01±0.08
IR	1.12±0.04	0.77±0.06	1.00±0.07	1.17±0.06	0.86±0.03	0.92±0.03
IR-no IR	**-0.04**	**0.04**	**-0.07**	**-0.03**	**0.05**	**-0.09**
percentage	**-3.8%**	**6.0%**	**-6.4%**	**-2.3%**	**6.0%**	**-8.9%**

CONCLUSION: This work demonstrates that MK is a more robust measurement regarding CSF contamination than either MD or FA. This is a significant advantage in assessing tissue changes associated with neuropathology and implies that MK may be a more specific indicator of alterations associated with tissue microstructure (e.g., membrane permeabilities) as opposed to gross brain volume changes which can lead to increased CSF contamination effects.

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