Effects of ischemic stroke on cerebral tissue microenvironment using diffusional kurtosis imaging

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Introduction

Conventional diffusion MRI (dMRI) has been extensively used for the clinical assessment of stroke due to its superior sensitivity to ischemic injury as compared to other imaging modalities (1). However, the presence of free fluid, such as CSF, may cause overestimation of the apparent diffusion coefficient (ADC) obtained from dMRI, thus confounding the assessment of microstructural changes associated with ischemia. It is therefore necessary to find an alternative technique that is more sensitive and specific to the microenvironment in neural tissues. Diffusional kurtosis imaging (DKI) which measures non-Gaussianity of water diffusion (2) is a potential candidate (3). Apparent diffusional kurtosis (K) measures tissue complexity due to the presence of cell membranes and organelles, and water compartments with differing diffusion properties (2). The goal of this study was to investigate diffusional kurtosis change in acute/subacute ischemic stroke.

Methods

MRI experiments were performed using a 1.5 T Avanto Siemens MR scanner on N=25 patients (mean ± SD of age: 60 ± 15) presenting with ischemic stroke symptoms. Time after onset ranged from 7.5 to 60 hours. DKI acquisition was performed with 3 b-values (0, 1000 and 2000 s/mm^2) along 30 diffusion encoding directions using single-shot twice-refocused-EPI with NEX=1 (NEX=10 for b=0). Other imaging parameters were: acquisition matrix = 74 x 74, image resolution = 3 x 3 x 3 mm^3, TR/TE = 5500/99 ms, BW/pixel = 1325 Hz. Fractional anisotropy (FA), mean (MD), axial ($\lambda_{//}$), radial diffusivity ($\lambda_{\perp}$), mean (MK), axial ($K_{//}$) and radial kurtosis ($K_{\perp}$) were computed using the in-house DKE software (4). All images were normalized to a T1-weighted template obtained from elderly volunteers and subsequently segmented into grey (GM) and white matter (WM) masks using a spm8 (http://www.fil.ion.ucl.ac.uk) toolbox by Chris Rorden (http://www.cabiatl.com/CABI). Multi-slice ROI covering the majority of the ischemic lesion were identified by the hyperintensity on the mean of all diffusion-weighted images (DWIs) with b-value of 2000 s/mm^2 ($mDWI_{2000}$). Lesion ROI were segmented based on the WM/GM masks of individual patient. Notice that since ischemia changes the contrast of T1-weighted images (reference image of the brain normalization), mirror images of the WM/GM masks in the normal hemisphere were used to estimate those of the lesion ROI.

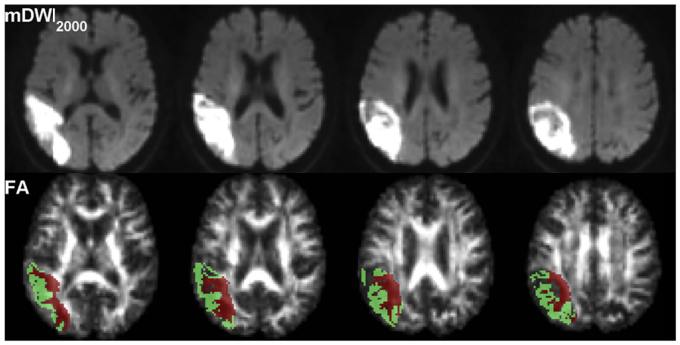

Fig.1 The mean of all DWI with b-value of 2000 s/mm^2 ($mDWI_{2000}$) and FA maps of a representative stroke patient. The WM (red) and GM (green) ROIs in the ischemic lesion were also overlaid on FA maps. Notice that the WM and GM ROIs do not cover the entire lesion because a threshold of 0.6 was used on the probabilistic WM/GM masks obtained from spm8.

Results and Discussion

Fig.1 shows the mean of all DWI with b-value of 2000 s/mm^2 ($mDWI_{2000}$) and FA maps of a representative stroke patient. The WM (red) and GM (green) ROIs in the ischemic lesion were also overlaid on FA maps. Notice that the WM and GM ROIs do not cover the entire lesion because a threshold of 0.6 was used on the probabilistic WM/GM masks obtained from spm8. **Fig.2** shows the percent changes, $(\mu_l - \mu_c)/\mu_c$, where μ_c and μ_l are the mean of contralateral and lesion ROI measurement, respectively, of the WM and GM in ischemic lesion for different diffusion metrics. Conventional diffusion metrics were all significantly reduced in the lesion, whereas those of DKI significantly increased. It is noteworthy that there was a larger percent change in axial than radial direction in ischemic WM. Specifically, for DTI metrics (axial vs. radial): 26 vs. 17%; For DKI: 48 vs. 24%. Another important finding is that the percent change in $K_{//}$ was significantly larger than in $\lambda_{//}$ while $\lambda_{\perp}$ and $K_{\perp}$ had similar percent changes. These results indicated that ischemia has a more dramatic effect on diffusion along the long-axis of axons. Similar results were also observed in a DTI study (5).

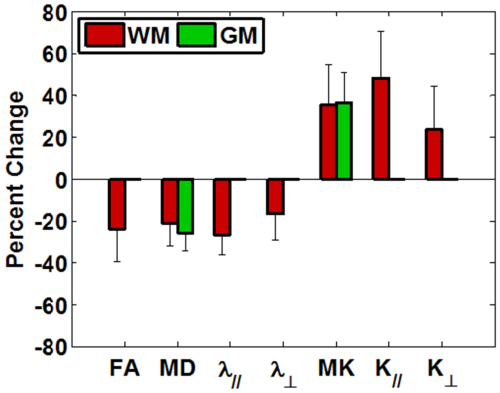

Fig.2 Percent changes, $(\mu_l - \mu_c)/\mu_c$, of the WM and GM in ischemic lesion as compared to contralateral hemisphere for different diffusion metrics. μ_c and μ_l are the mean of contralateral and lesion ROI measurement, respectively.

The current findings from a cohort of 25 patients confirm the results of our preliminary study (3). Notice that ROIs encompassing the majority of the ischemic lesion were used in the current study rather than only the regions with highly orientated axons, thus providing a more comprehensive characterization of the changes in cerebral tissue microenvironment under ischemia. In summary, the current study illustrates how diffusion metrics obtained from DKI can potentially complement those of DTI for improving stroke assessment.

References 1. Baird AE, Warach S. J Cereb Blood Flow Metab 1998;18(6):583-609. 2. Jensen JH et al. Magn Reson Med 2005;53(6):1432-1440. 3. Jensen JH et al. NMR Biomed 2011;24(5):452-457. 4. Tabesh A et al. Magn Reson Med 2011;65(3):823-836. 5. Tamura H et al. Magn Reson Med Sci 2009;8(3):121-134.