Change in Axial and Radial Diffusional Kurtoses for Ischemic Stroke

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Introduction

Diffusion-weighted imaging (DWI) is widely applied for the clinical assessment of ischemic stroke. Most notably, a drop in the Mean Diffusivity (MD) of roughly 50% typically occurs within the affected region [1]. For the same ischemic region, the Mean diffusional Kurtosis (MK), which is an indicator of diffusional heterogeneity, may also increase substantially [2-4]. In this study, we further investigated this phenomenon by measuring, in addition to the MD and MK, the axial and radial diffusional kurtoses in three patients with focal ischemic stroke.

Methods

The diffusional kurtoses were estimated by applying the DWI method of Diffusional Kurtosis Imaging (DKI) [5, 6] to scan three patients with subacute focal ischemic stroke confined to a single brain hemisphere. MRI scans were performed between 13 and 26 hours following the onset of symptoms. With DKI, we obtained parametric maps for the MK, axial kurtosis (K_{ax}), and radial kurtosis (K_{rad}). K_{ax} is defined as the diffusional kurtosis in the direction parallel to the diffusion tensor eigenvector corresponding to the largest eigenvalue, while K_{rad} is defined as the diffusional kurtosis averaged over all directions perpendicular to this eigenvector. Our definition for K_{ax} corresponds to that of Hui et al. [7], but our definition for K_{rad} is different. For one patient, three b-values were used (0, 1000, 2000 s/mm^2), with the other imaging parameters being: # diffusion directions = 30, slice thickness = 5 mm, TE = 96 ms, TR = 4500 ms, and in-plane resolution = 2.6 mm × 2.6 mm. For the other two patients, six b-values were used (0, 500, 1000, 1500, 2000, 2500 s/mm^2), with the other imaging parameters being: # diffusion directions = 30, slice thickness = 5 mm, TE = 104 ms, TR = 1500 ms, and in-plane resolution = 2 mm × 2 mm. All scans were performed on a Siemens 1.5T Avanto scanner. In addition to MK, K_{ax}, and K_{rad}, the DKI dataset was also used to calculate, as references, parametric maps for the MD, fractional anisotropy (FA), axial diffusivity (D_{ax}), and radial diffusivity (D_{rad}).

For each subject, a region of interest (ROI) was drawn on a single slice within the ischemic region, as identified on the MD maps, and a corresponding ROI of identical size was drawn on the contralateral side. For one patient, the ROI contained 36 voxels, while for the other two they contained 12 voxels. Values for each of the diffusion metrics were obtained by averaging the maps over the ROI, and "percent changes" were calculated from 100[*X*(ischemic) – *X*(contralateral)]/ *X*(contralateral), where *X* represents any of the diffusion metric values.

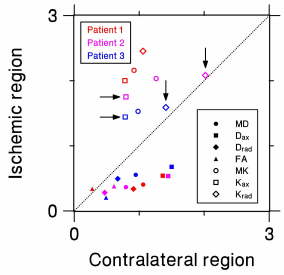

Figure 1. Diffusion metric values for ischemic regions vs. values for contralateral regions. For two patients, K_{rad} showed little change (vertical arrows), although K_{ax} changed substantially (horizontal arrows). The line of slope one is included as a visual reference.

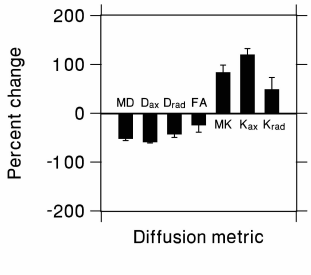

Figure 2. Average percent changes in the diffusion metric values for the three patients. The largest change is for K_{ax}, which is over twice that for K_{rad}. The error bars indicate standard deviations.

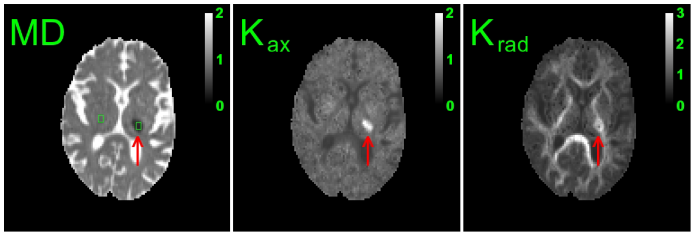

Figure 3. Parametric maps of MD, K_{ax}, and K_{rad} for a single patient (Patient 2), obtained from MRI scans taken 24 hours after the onset of symptoms. The ischemic region in the left thalamus and posterior limb of the left internal capsule is indicated by red arrows and the ROI by green boxes in the MD map. Note that the ischemic region stands out more clearly in the K_{ax} map than in the K_{rad} map, indicating that the diffusional kurtosis changes are more pronounced in the axial direction. The scale bar for the MD map is in units of μm^2/ms, while those for K_{ax} and K_{rad} are unitless.

Results

Figure 1 shows diffusion metric values for the ischemic regions versus the corresponding values for the contralateral regions. The diffusivities are in units of μm^2/ms, while the FA and kurtoses are dimensionless. Error bars are not displayed, since the standard errors are too small for these to show clearly reflecting a high degree of uniformity within the ROI. A line with a slope of one is included as a visual guide to indicate no change between the ischemic and contralateral sides; the farther a point lies from this line the larger the differences between the ischemic and contralateral diffusion metric values. For all three subjects, the MD is substantially lower and the MK is substantially higher in the ischemic region, in consistency with prior studies [1-4]. However for two of the patients, K_{rad} is nearly unchanged at the same time that K_{ax} increases by roughly 100%. The average percent change for each metric is given by Fig. 2. The largest percent change is for K_{ax}, which exceeds that for K_{rad} by more than a factor of two. The magnitude of the change for D_{ax} is also larger than that for D_{rad}, but to a lesser degree. The MD, K_{ax}, and K_{rad} maps for one patient are shown in Fig. 3, demonstrating a relatively larger diffusional kurtosis increase in the axial direction as compared to the radial direction.

Discussion

For this preliminary study, we observed a large change in K_{ax} for all three patients, but K_{rad} did not change substantially for two of these. The two patients with small K_{rad} changes had high contralateral FA values (0.49 and 0.61), indicating regions comprised mostly of white matter. This suggests that, for white matter, ischemia increases diffusional heterogeneity primarily in the axial direction. This observation, if confirmed in studies with more subjects, may provide an important constraint on the various and still debated models of how ischemia alters diffusional properties in brain [8, 9]. For example, the large change in K_{ax} may be related to ischemia-induced axonal varicosities [10].

References: **1.** Schlaug, et al. Neurology 1997;49:113. **2.** Jensen & Helpern. Proc Intl Soc Mag Reson Med 2003;11:2154. **3.** Lätt, et al. Proc Intl Soc Mag Reson Med 2009;17:40. **4.** Helpern, et al. Proc Intl Soc Mag Reson Med 2009;17:3493. **5.** Jensen, et al. MRM 2005;53:1432. **6.** Lu, et al. NMR Biomed 2006; 19:236. **7.** Hui, et al. Neuroimage 2008;42:122. **8.** Silva et al. MRM 2002;48:826. **9.** van Pul, et al. MRM 2005;53:348. **10.** Hou, et al. J Neurochem 2009;111;870.

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