The Employment and Validation of Keyhole Imaging Technique in MR Spin-Echo Diffusion Tensor Imaging

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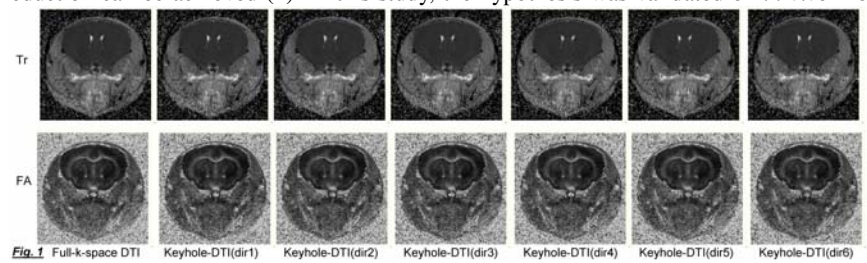
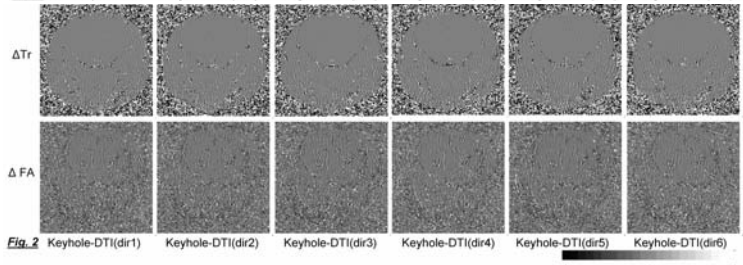
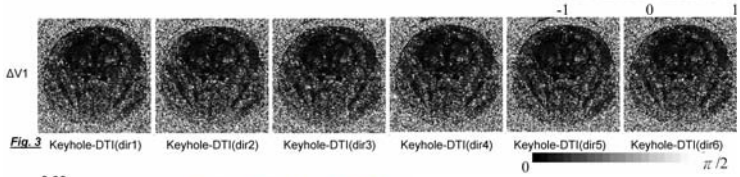
Introduction

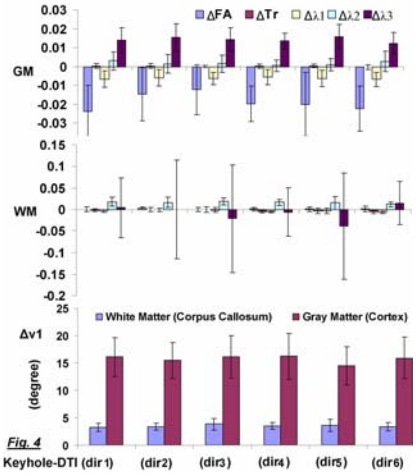
Diffusion tensor imaging (DTI) has become an important imaging technique in investigating and diagnosing the disorders of human central nervous system. However, the conventional spin echo diffusion-weighted imaging sequence used for acquiring DTI data is time consuming. To speed up the data acquisition, echo-planer imaging (EPI) sequence has been widely used. However, EPI suffers from the field homogeneity and magnetic susceptibility effect. The eddy current effects in EPI can also cause severe imaging artifacts.

In this study, an alternative solution for fast DTI was validated. For calculating the diffusion tensor indices, six diffusion-weighted images (DWI) with the same b values but different diffusion encoding directions plus one null image with b = 0 were acquired. These images showed similar tissue structures but different signal intensities. This method (keyhole-DTI) is based on the hypothesis that high frequency signals of DWIs, which reflect majority the edges of tissue structures, do not vary much among these DWIs and therefore can be shared between each other. Thus, by acquiring the full k-space data of only one DWI, and sharing the high frequency components to the rest DWIs, a significant acquisition time reduction can be achieved (1). In this study, the hypothesis was validated on *in vivo* mouse brain DTI. The high frequency k-space data used to share with every DWI was taken from each of the six DWIs, respectively.









Materials and Methods

Six normal mice were anesthetized with a mixture 2% soflurane/oxygen. Data were acquired using Oxford Instruments 200/330 (4.7 T) magnet and spin-echo DWI sequence with TR 1.5 sec, TE 70 ms, slice thickness 0.5 mm, field-of-view 3 cm, and data matrix 256 × 256. A b of 850 mm^2/s was applied on six icosahedral diffusion encoding directions (x, y, z) including dir1=(0.85, 0, 0.53), dir2=(-0.85, 0, 0.53), dir3=(0, 0.53, 0.85), dir4=(0, -0.53, 0.85), dir5=(0.52, 0.85, 0), and dir6=(0.53, -0.85, 0). The approach of keyhole-DTI was to replace the top 25% and bottom 25% k-lines of one of the six DWIs to those respective k-lines in the other five DWIs. The data of keyhole-DTI was denoted as keyhole-DTI(***dirn***), where ***dirn*** is one of the ***n*** diffusion encoding directions (***n*** *= 1 - 6* in this case). DTI indices, including fractional anisotropy (FA), Tr, three eigenvalues (λ_1, λ_2, λ_3), and the major eigenvector (v1) were calculated in white matter (WM, corpus callosum) and gray matter (GM, cortex). Paired t-test was used to compare the DTI parameters obtained from full-k-space DTI and keyhole-DTI. $P < 0.05$ is considered significant.

Results

Figure 1 showed the representative Tr and FA maps of Full-k-space-DTI and keyhole-DTIs of one mouse brain. There was no noticeable difference between Full-k-space-DTI and keyhole-DTI and between the keyhole-DTIs. In order to better characterize the changes caused by keyhole-DTI, the change ratio of DTI indices between full-k-space and keyhole-DTI, *i.e.*, (keyhole-DTI – full-k-space-DTI)/full-k-space-DTI, was also calculated. The change ratio was denoted by adding a Δ in front of DTI indices. With pixel-by-pixel calculation, change ratios of Tr and FA from the same mouse of Fig.1 were shown in Fig.2. Again, with the exception in the low signal regions, such as the skull and air, no significant in change ratios were noticeable. The error to v1 estimation of keyhole-DTI was quantified by calculating the dispersion angle between keyhole-DTI and full-k-space-DTI and denoted as Δv1. As shown in Fig. 3, Δv1 is larger in GM than those in WM, but no significant difference was found in between keyhole-DTIs. Figure 4 summarized the change ratios of DTI indices measured from all six mice. In GM, keyhole-DTI tended to underestimate FA and overestimate λ_3 but those values were not significant. In WM, larger standard deviation was found in λ_3 than other DTI indices, but there were no significant changes caused by keyhole-DTI. The significant effects caused by keyhole-DTI could be found in Δv1, where 3 ± 0.8 and 16 ± 4 degree dispersion angles were measured in WM and GM respectively.

Discussion and Conclusions

This study investigated the effects of keyhole-DTI in live mouse brain. Except for the relatively large dispersion angle of the major eigenvector in GM, the effects of keyhole procedures are small and insignificant to all other quantified DTI indices. Total acquisition time was reduced from 3h to 1.9h or ~36%. This promising characteristic can be extensively employed in studies faced with serious susceptibility and eddy current artifacts, as those commonly seen in nasal area of EPI-based DTIs.

References 1. Hsu EW, et al, J Card Magn Reson 3(4), 339-347, 2001.

Acknowledgement: *NMSS: RG 3864, CA 1012-A-13; NIH: R01 NS 047592, R01 NS 054194.*