7T Diffusion Imaging of Rat by Using SNAILS and Its Application in Stroke Study

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INTRODUCTION Diffusion-Weighted Imaging (DWI) can assist physicians in the quality of diagnosis, treatment and outcome prediction, greatly enhancing the care available for stroke patients. Animal stroke studies with DWI are widely investigated to facilitate the development of stroke diagnosis [1]. However, diffusion imaging on small animals at high fields is usually very challenging due to the resolution-SNR tradeoff and hardware imperfection. The widely used single shot Echo Planar Imaging (ssEPI) DWI technique is particularly vulnerable to these factors and tends to produce severe image artifacts. In this work, we demonstrate the implementation of the self-navigated interleaved spirals (SNAILS) technique [2] on our 7T animal scanner. High quality DWI images can be acquired for stroke studies on rats. The preliminary diffusion tensor imaging (DTI) results also seem promising for future animal DTI studies.

METHODS Compared with clinical human DWI, there exist several challenges for rat DWI under high field. First, the inhomogeneity of main magnetic field (B0) is expected to be stronger at high field, which will prohibit the usage of long acquisition readouts. Second, a small-bore animal scanner usually has much stronger gradient powers and slew rates, which can be utilized to accelerate generating diffusion-sensitizing gradients. However, this may cause larger eddy currents as well, from both diffusion weighting and readout gradients. Next, DWI images yield much lower SNR compared with anatomical scans, especially at high resolution, which is typically required for small animals due to their limited field of view (FOV). Finally, motion artifacts may be stronger due to their faster heart rates. These potential issues will hamper the performance of ssEPI-DWI in high field animal experiments.

SNAILS is a multi-shot spiral DWI technique. In this method, interleaved variable-density (VD) spirals are used to acquire k-space data. The length of the spiral readout can be freely chosen. Since each VD-spiral arm oversamples the k-space center, an unaliased low resolution map can thus be extracted from it to correct motion induced phase errors. This redundancy sampling of inner k-space also provides extra SNR boost. Compared with ssEPI, a shorter TE may be achieved in SNAILS to further reduce the SNR loss since each spiral shot samples the k-space origin at the beginning of acquisition. In addition, the continuously oscillating pattern of spiral gradients makes it insensitive to eddy currents.

The SNAILS sequence was implemented on our animal scanner. This is a self-shielded GE microSigna 7.0T scanner with a 310mm horizontal bore. To improve the accuracy of spiral samplings, the gradient delay on each gradient coil was measured [3] and corrected in SNAILS. The option of B0 map estimation and correction is also available in SNAILS. But it doesn't seem to be crucial in our implementation since we usually use short spiral readouts.

RESULTS In vivo rat DWI experiments were performed on both stroke and non-stroke animals. A female Wistar rat was given one hour of Middle Cerebral Artery Occlusion (MCAO), where a coated filament was introduced through the internal carotid artery and advanced till it occluded the right middle cerebral artery. This would reduce blood flow to replicate a stroke onto its right hemisphere. The filament was removed after 1 hour to allow reperfusion of the MCA. Both b0 and a series of DWI images were acquired at different b-values, ranging from 600s/mm^2 to 3000s/mm^2, by using a quadrature head coil. Following scan parameters were used: TE/TR=25ms/3s, FOV=6mm, matrix size=128x128, slice-thickness=1mm, num-of-slices=20, num-of-shots=12, length-of-spiral~=4ms, NEX=1. The total scan time was 36s for each set of images. Selected images from a similar slice location are shown in Fig 1. DTI data were also acquired on the healthy animal, with 6(+1) diffusion directions and b-values of 1000s/mm^{2}and 1000s/mm^2. Calculated FA map are shown in Fig 2.

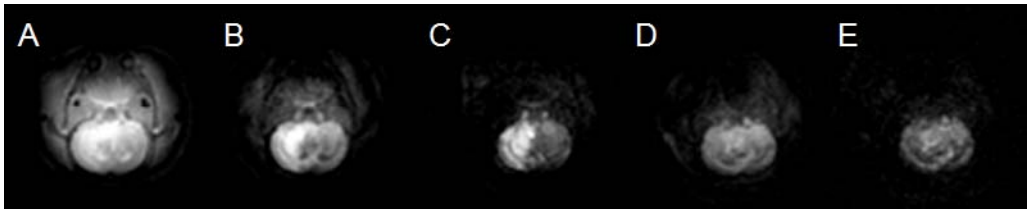

Figure 1: SNAILS images of rat DWI:
A – b0 image of the stroke animal;
B – b=1000 s/mm^2 of the stroke animal;
C – b=2500 s/mm^2 of the stroke animal;
D – b=1000 s/mm^2 of the normal animal;
E – b=2500 s/mm^2 of the normal animal.

DISCUSSION AND CONCLUSION From Fig 1, it can be seen that the stroke area doesn't clearly show up on the b0 image (Fig 1A). As diffusion weighting (b-value) increases, contrasts of the stroke area will become more and more intense on the right hemisphere (left of the image), as shown in Fig 1B and 1C. This hyperintensity is evidentially caused by stroke lesions when comparing the images from the stroke animal with those from the normal animal (Fig 1D and 1E). Fig 2 shows some promising results for this DTI study as well. More diffusion anisotropy seems to be produced with a higher b-value. However, with higher diffusion weighting, there would be greater signal loss as well due to the residual motion induced phase errors. More DTI studies are expected to be conducted and advanced improvement solutions will be investigated. These include further reducing motion artifacts, correcting spiral blurring, improving the B0 shimming, and etc. In conclusion, SNAILS is a feasible approach for doing animal stroke DWI at high field. With a much better performance than ssEPI, it will also facilitate other animal DWI and DTI experiments in the future.

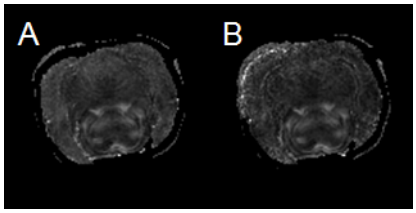

Figure 2: FA maps of a normal rat.
A – b=1000s/mm^2; B – b=2000s/mm^2.

REFERENCE 1. Moseley ME., et al., Magn Reson Med, 1990, 14:330-346; 2. Liu C., et al., Magn Reson Med, 2004, 52:1388-1396; 3. Duyn JH., et al., J Magn Reson, 1998, 132:150-153

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