Diffusion Weighted Fast Spin Echo PROPELLER at 9.4T

I. Teh[1,2], D. J. Larkman[1], and X. Golay[2,3]

[1]Imaging Sciences Department, MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, United Kingdom, [2]Laboratory of Molecular Imaging, Singapore Bioimaging Consortium, Singapore, Singapore, [3]Department of Neuroradiology, National Neuroscience Institute, Singapore

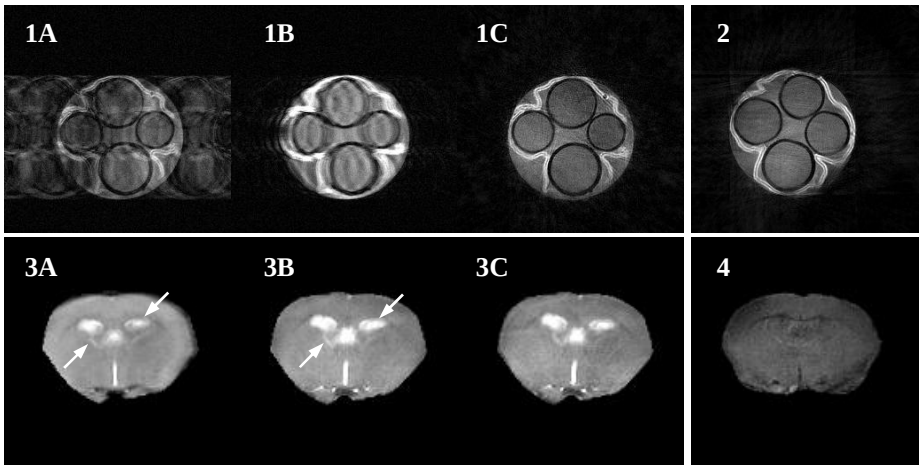
Introduction

Diffusion weighted imaging (DWI) is widely used in clinical and preclinical imaging for studying tissue integrity and structure. In the preclinical setting, diffusion weighted (DW) spin echo methods suffer from long acquisition times and intolerance to motion. Single shot echo planar imaging is widely used to improve motion robustness and efficiency, but suffers from lower resolution and magnetic field inhomogeneity effects. At high fields, image distortion and short T_2* make multishot fast spin echo (FSE) methods more attractive. The self navigating properties of Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction (PROPELLER) have been demonstrated [1] and combined with DW-FSE in the clinic [2] as an efficient sequence robust to motion artifacts and image distortion. Here, DW-FSE-PROPELLER is applied in in-vivo imaging of mice at 9.4T.

Methods & Materials

A single shot DW-FSE pulse sequence was implemented. The sequence comprised a spectrally selective 90° fat saturation pulse, followed by a 90° excitation pulse, a pair of pulsed gradient spin echo diffusion gradients about the first 180° refocusing pulse, and an FSE readout. In PROPELLER, each k-space blade was acquired within a single shot and the FOV was progressively rotated with each TR. The k-space peaks across all blades were aligned to correct for linear phase errors due to rigid motion. Non-linear phase errors can be corrected by normalizing the image phase in each blade to that of the first blade in the central region where the blades overlap. The blades were then regridded onto a Cartesian k-space and the Fourier transform was used to obtain the image. Image reconstructions were performed offline using MATLAB™ (The MathWorks, Natick, MA).

Gel phantom data were acquired on a Varian 9.4T scanner (Varian Inc., Palo Alto, CA) using both DW-FSE-Cartesian and DW-FSE-PROPELLER methods. A reference non-DW image and three DW images with diffusion gradients applied in orthogonal directions were acquired to obtain mean Apparent Diffusion Coeffiecient (ADC) data. Physiological motion was induced using a balloon that was periodically inflated using a ventilator. The balloon was placed beneath one end of the gel cylinder, resulting in a largely in-plane motion of 1mm at the slice-of-interest. Imaging parameters were TR=1000ms, Effective TE=30ms, Echo Spacing Esp=13ms, Echo Train Length=8, $Matrix_{Cartesian}$=256x256, $Matrix_{PROPELLER}$=256x8, Number of blades N=50, FOV=25x25mm^2, thickness=1mm, NEX=1, DW Gradient Strength, G_{diff}=25.6G/cm, DW Gradient Duration δ=4ms, DW Gradient Separation Δ=8ms, B-value b=500s/mm^2, and ventilator-induced oscillation rate=78/min. Isotropic DW datasets were acquired using Cartesian and PROPELLER methods. For comparison a triggered Cartesian dataset was also acquired where the acquisition was triggered by the induced motion (Figs. 1A-C). The effects of undersampling on reconstructed DW-FSE-PROPELLER data were explored in a separate experiment (Fig. 2) with TR=1500ms. For comparison, the acquisition time given was reduced by a third to keep the TR identical to the first experiment. In-vivo brain data were acquired using C57 and Bl6 wildtype mice weighing 25-30g at P45-50. The mice were anaesthetized using 3% isoflurane (induction) and 1.2% isoflurane (maintenance), and secured with a bite bar and nosecone. The mice were free breathing and maintained between 70-80 breaths per min. Imaging parameters were similar to those used for the phantom experiments, except for the following changes: TR=4000ms, Effective TE=31ms, Esp=18ms, G_{diff}=36.2G/cm and b=1000s/mm^2.



Figures 1A-C. DW images for non-triggered Cartesian, triggered Cartesian, and non-triggered PROPELLER data respectively, where b=500s/mm^2 and corresponding acquisition times (AT) = 2m10s, 3m19s and 3m22s. **Figure 2.** Undersampled PROPELLER DW image where N=32 and the adjusted AT=2m10s. **Figures 3A-C.** In-vivo non-DW images of a mouse brain for Cartesian, fully sampled (N=50) and undersampled (N=32) PROPELLER data respectively, where corresponding AT = 8m40s, 13m26s and 8m40s. **Figure 4.** In-vivo DW image using fully sampled PROPELLER where b=1000s/mm^2 and AT=13m26s. In-vivo acquisitions were non-triggered.

Results & Discussion

In DWI, motion combines with large diffusion gradients to produce significant intershot phase errors. In non-triggered Cartesian data, these may manifest as ghosting artifacts in the phase encode direction and/or motional blurring. The artifacts are reduced but not eliminated when triggering is used (Fig. 1B). However, triggering increases the scan time and also gives rise to variable TR in free breathing experiments which compromises contrast. The rotational acquisition and phase correction in the PROPELLER acquisition eliminates the ghosts and the image quality is improved. Although fully sampled PROPELLER takes about 50% longer than a similar Cartesian acquisition, the prolonged scan time can be reduced by undersampling the number of blades while producing minimal image artifacts [3]. Experiments using a water phantom suggest that up to 33% blade undersampling does not significantly affect the image quality or the measured mean ADC (data not shown). Furthermore, in PROPELLER, motion-corrupted blades can be rejected and the sequence of blade acquisition can be ordered to minimize the effects of missing blades [4]. In-vivo non-DW images show that undersampled PROPELLER can be applied in-vivo while maintaining the scan time of a similar Cartesian acquisition (Figs. 3A-C). The contrast and resolution of a fully sampled DW-FSE-PROPELLER acquisition at b=1000s/mm^2 is demonstrated (Fig. 4). In conclusion, multishot Cartesian DW-FSE suffers from artifacts in the presence of motion. These artifacts are reduced significantly using DW-FSE-PROPELLER. A comparison of Figures 3A and 3B shows that the PROPELLER acquisition maintains high resolution even in the presence of motion (See areas highlighted by the arrows). While motion can be minimized through the use of a bite bar, head frame, intubation and/or muscle relaxant, these can cause injury or death in the animal. This risk can be avoided using PROPELLER. PROPELLER was successfully implemented at 9.4T for DWI of mice in-vivo and these preliminary results suggest that PROPELLER's ability to enhance resolution in the presence of motion will make it a valuable tool in small animal imaging where resolution is always compromised.

References

[1] Pipe J.G., MRM, 1999, 42, 963-969; [2] Pipe J.G. *et al*, MRM, 2002, 47, 42-52; [3] Arfanakis K. *et al*, MRM, 2005, 53, 675-683; [4] Nehrke K. *et al*, Proc ISMRM 2007, 1729. The authors wish to acknowledge the Agency for Science, Technology and Research, Singapore for funding.