Multi-Echo PROPELLER Imaging

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Introduction

PROPELLER, developed by Pipe *(1)*, is a multi-shot imaging technique that can be used to reduce motion artifacts without explicitly acquiring navigator echoes. When used for diffusion imaging, PROPELLER offers a number of advantages over a single-shot echo planar pulse sequence, most notably reduced sensitivity to magnetic susceptibility variations and eddy currents. The use of multi-shot excitations, however, results in long data acquisition times. This problem is exacerbated when signal averaging is also needed to achieve an adequate signal-to-noise ratio (SNR). Recently, turbo-PROPELLER was introduced by employing a GRASE sequence *(2)* to reduce the data acquisition time and improve the robustness against motion *(3)*. However, the reconstruction algorithm must be modified to account for the varying phase sensitivity between the gradient echoes. Here we report a multi-echo PROPELLER sequence where each gradient echo is used to form a separate image, thereby avoiding the problem with inconsistent phase errors. Among many applications, images from the multi-echo PROPELLER sequence have been used to assess the T2* effects, and magnitude-averaged to demonstrate the improved SNR in diffusion-weighted imaging.

Methods

Pulse Sequence: The multi-echo PROPELLER pulse sequence is diagrammed in Fig. 1. The sequence consisted of *N* (e.g., *N*=8-16) RF refocusing pulses to produce a CPMG spin echo train. Each spin echo was split into *M* (e.g., *M*=3-5) gradient echoes by a bipolar readout gradient. Unlike turbo-PROPELLER *(3)*, all *M* gradient echoes were assigned to the same phase-encoding value. Thus, a total of *M* individual images were produced when all shots were completed. (Note that each shot samples *M* identical k-space blades, as shown in Fig.1.) Since k-space data corresponding to different gradient echo indices were not combined, the problem with phase inconsistency was considerably reduced. This eliminated the need to perform phase correction among the gradient echoes. To vary the degree of T2* weighting at different gradient echoes, a user controllable delay time was introduced between the lobes of a bi-polar readout gradient. In addition, a diffusion-weighting gradient was also incorporated into the pulse sequence (not shown in Fig. 1).

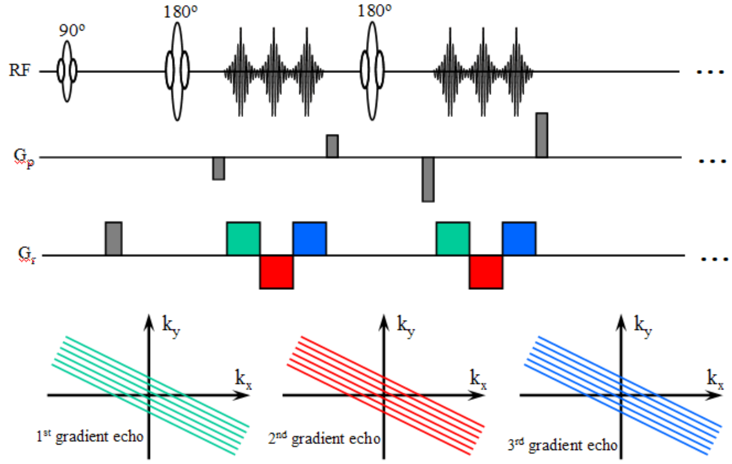

Fig. 1 A multi-echo PROPELLER sequence. G_r and G_p are the readout and phase-encoding gradients, respectively. k-Space lines with the same color are grouped together to form an image.

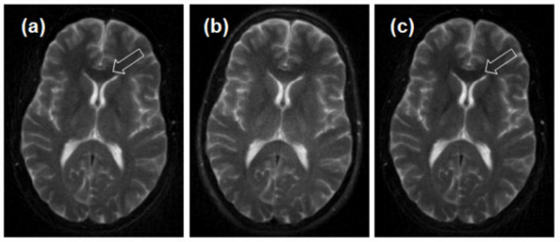

Fig. 2 Multi-echo PROPELLER images acquired using the first (a), second (b), and third (c) gradient echo in Fig. 1, respectively. Notice the increased T_2* contrast as pointed by the arrows in (a) and (c).

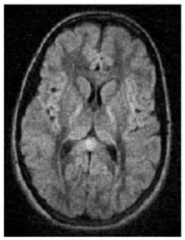

Fig. 3 A diffusion-weighted image from the multi-echo PROPELLER sequence.

Data Acquisition: The multi-echo PROPELLER pulse sequence was implemented on a General Electric 1.5T NV/*i* scanner. After a number of phantom experiments to validate the pulse sequence, two sets of brain images were acquired from a healthy human subject using a quadrature birdcage coil. The first image set was intended to demonstrate the different degree of T2* weighting among the multi-echo images. The second image set was used to illustrate the SNR improvement in diffusion-weighted imaging (b=2000 s/mm^2) by averaging the images from the individual gradient echoes. The key data acquisition parameters for both series were: TR = 4000ms, TE = 77.3ms, *N* (spin echo train length) = 16, *M* (gradient echo train length) = 3, number of blades = 24, readout size = 256, FOV = 24cm, and slice thickness = 5mm.

Image Reconstruction: After flipping the k-space lines acquired with negative readout gradient, magnitude image reconstruction was individually performed on data acquired from each gradient echo using the algorithm described in *(1)*. The images were displayed individually for the T2* series, while they were averaged for the diffusion series.

Results and Discussion

The three images from the T2* series are shown in Fig. 2. Even with a very short gradient-echo spacing of ~2ms, the effect of T2* (as well as chemical shift) was visible in images (a) and (c), in comparison with the fully refocused image in (b). The T2* effect was enhanced as the gradient echo spacing increased. The diffusion-weighted images exhibited good quality, although streak artifacts were observed in the background, presumably due to off-resonance effects. When the three multi-echo diffusion images were averaged (Fig. 3), the SNR was increased by 62-68% in several selected white-matter regions.

We have demonstrated that the multi-echo PROPELLER sequence can be used to assess the T2* effects and to increase the SNR by amplitude-averaging the individual images. Examples of potential applications of the pulse sequence include (but are not limited to) quantitative T2* mapping, magnetic susceptibility-weighted imaging, fat-water in/out phase imaging, and fat-water separation using the Dixon methods.

References

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3. Pipe JG. *Abstracts of the10th ISMRM Meeting* 2002; Honolulu, Hawaii; p 435.