# Reduction of Shading Artifact with Center-Out View Order for Diffusion-Weighted PROPELLER

**X. Zhao[1], A. Gaddipati[1], S. Chang[1], and D. Gui[1]**
[1]GE Healthcare, Waukesha, Wisconsin, United States

**Introduction** Robust Fast Spin Echo (FSE) pulse sequence typically requires that the transverse magnetization be aligned along the axis of refocus pulses, comprising the so-called Carr-Purcell-Meiboom-Gill (CPMG) condition. If CPMG condition is not satisfied, the echo signal may not be maintained and fast signal decay occurs. For FSE-based diffusion-weighted PROPELLER imaging (1), the application of diffusion gradients may introduce spatially varying and unknown phases that violate the CPMG condition. One method to address the non-CPMG problem is x-y quadratic phase cycling (2, 1), the phase of the refocusing pulse is alternated between the x and y axes. However, this method still requires that the flip angle of the refocusing pulses should not be too far way from 180 degree. In practice, the desirable flip angle range is 180 ± 25 degrees. Due to $B_1$ inhomogeneity caused by dielectric effect and transmit coil property, this range may not be easily satisfied across the whole brain for a 3T scanner (3). Flip angles beyond this range fail to maintain the echo signal and cause significant shading artifact. One example of the shading is shown in Figure 1b, where inner brain is much darker than the outer brain because the spins were over-flipped.

In the present work, a "center-out" view order is demonstrated to significantly reduce the shading artifact. For each blade in PROPELLER acquisition, the echo train is phase encoded in the way the early echoes are placed near the center k-space. Since the early echoes are not decayed out yet and the signal from center k-space is the predominant factor that determines the image contrast and signal level, the shading artifact is reduced. Besides the shading reduction, center-out view order also has the benefit to improve the overall SNR across the whole brain because the TE is much reduced.

**Methods** Without loss of generality, per-blade view number 8 is assumed in the following explanation. For center-out view order, the echoes are phase-encoded in the order of {0, $-\Delta k_y$, $\Delta k_y$, $-2\Delta k_y$, $2\Delta k_y$, $-3\Delta k_y$, $3\Delta k_y$, $-4\Delta k_y$}. It is noted the first echo is placed at the center k-space, and the earlier an echo is, the closer to the center k-space. This is compared with the typical sequential view order of {$-4\Delta k_y$, $-3\Delta k_y$, $-2\Delta k_y$, $-\Delta k_y$, 0, $\Delta k_y$, $2\Delta k_y$, $3\Delta k_y$}, where the echoes are sequentially placed in k-space in the timing order.

Diffusion-weighted PROPELLER was performed on a GE 3T scanner to image a normal volunteer. The parameters were 128 diameter matrix over 22 cm FOV, 5 mm slice thickness, 16 ETL with split-blade (4), 1000 s/mm$^2$ b-value and 5000 ms TR. for each slice, 3 diffusion-weighted images with orthogonal diffusion-weighting directions were obtained and combined together to generate the combined diffusion-weighted image. Both center-out and sequential view orders were scanned. Center-out view order has a TE = 72.6 ms and sequential view order has a TE = 109 ms.

**Results and Discussion** As shown in Figure 1, the center-out view order significantly reduced the shading artifact in the combined diffusion-weighted image; the inner brain darkness was reduced with a SNR increase around 60%. Because of the reduced TE, the outer brain SNR was also improved by around 20%. It is noted that the two images have different contrast due to the different TE values. The image with sequential view order is more $T_2$-weighted due to a longer TE value. Hence, the image with center-out view order has less interference from T2 weighting.

**References**

(1) JG Pipe, et al. MRM 2002;47:42-52. (2) AA Maudsley. JMR 1986;69:488-491. (3) M Alecci, et al. MRM 2001;46:379-385. (4) JG Pipe, et al. US Patent; US6882148B2.

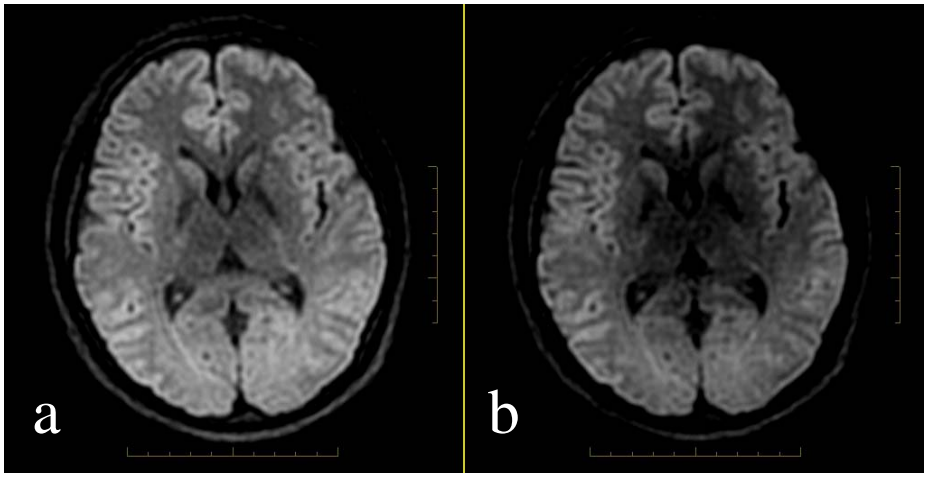


Figure 1. The combined diffusion-weighted images with (**a)** center-out view order and (**b)** sequential view order. The two images have the same window contrast level.