Reduction of Aliasing Artifacts in Diffusion-Weighted PROPELLER Imaging

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Introduction Diffusion imaging is typically performed in axial planes. This is largely due to its reliance on single-shot echo-planar imaging (EPI) which suffers from increased image distortion in sagittal and coronal planes because of concomitant gradient fields [1-2], especially with strong gradients and/or at relatively low B_0-fields (including 1.5T). Diffusion-weighted (DW) imaging in non-axial planes is preferred in some applications (e.g., visualization of corticospinal tracts using DTI), but has been hindered by EPI-based acquisitions. Recently, FSE-based PROPELLER (periodically rotated overlapping parallel lines with enhanced reconstruction) diffusion sequences have been developed as an alternative to EPI [3-5], opening the possibility to perform diffusion imaging in sagittal or coronal planes. In PROPELLER sampling, however, the phase-encoding axis is not fixed to a specific direction. When the phase-encoding direction is rotated to the superior/inferior direction in sagittal or coronal planes, aliasing can occur in some blades, producing non-localized streaking artifacts across the image. We describe a "slice tilting" technique to reduce the streaking artifacts in PROPELLER imaging and demonstrate the feasibility of using this technique to obtain DW images in sagittal and coronal planes with improved image quality.

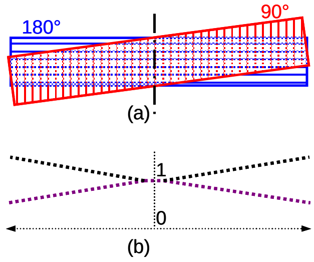

Figure 1: (a) Slice orientation during 90° and 180° RF pulses; (b) Theoretical profile of signal loss in the phase-encoding direction (in purple), and the kernel for intensity correction (in black).

Materials and Methods A DW PROPELLER sequence was modified to introduce a small "slice-selection" gradient (G_{yt}) in the phase-encoding direction (in our case, the short axis of the blade) during the 90° excitation RF pulse (Figure 1). With this gradient, the slice selected by the 90° pulse is tilted by $\theta = \arctan(G_{yt}/G_z)$ from the prescribed slice orientation (Note that G_z is the nominal slice selection gradient). Due to the tilt, spins excited during the 90° pulse do not overlap completely with those selected by the RF refocusing pulses (Fig.1a). With an optimally selected tilt angle for a given slice thickness, signal contributions from the regions beyond the FOV can be reduced while the signals within the prescribed FOV are minimally affected. For a given FOV and slice thickness, the tilt angle was chosen such that there was minimal signal contribution from aliasing-prone regions beyond the FOV. The optimal tilt angle under most imaging conditions was rather small (e.g., ~2° for a slice thickness of 5mm).

Experimental studies were carried out on a 1.5 T GE Signa HD scanner (GE Healthcare, Waukesha, WI). Sagittal and coronal DW images were acquired on both phantoms and a human volunteer to demonstrate the performance of the technique. The acquisition parameters included: TR/TE = 4000/93ms, ETL = 16, bandwidth = ±125kHz, 48 blades, 256 readout points, FOV = 28cm, slice thickness = 5mm, and tilt = 2°. Diffusion weighting was applied along the anterior/posterior direction for the sagittal images, and along the right/left direction for the coronal images, both with b = 750 s/mm^2.

The loss in signal intensity (s; shown in purple in Fig. 1b) due to slice tilting was described by the following function:

$$s = \begin{cases} 1 & 0 < d \le \tan\left(\theta/2\right) th/2 \\ -d.\tan\theta/th + (1+\sec\theta)/2 & \tan\left(\theta/2\right) th/2 < d \le \cot\left(\theta/2\right) th/2 \\ 0 & \cot\left(\theta/2\right) th/2 < d \end{cases}$$

where th is slice thickness, d is the distance from the center of the FOV, and θ is the applied tilt angle. To compensate for the signal loss, a correction kernel (schematically shown in black in Fig. 1b) was derived from the above equation, and was applied to each blade of the dataset after motion and phase correction [3], but before the final gridding reconstruction. To quantitatively evaluate artifact reduction, the strength of the streaking artifacts was calculated as a ratio of the mean intensity of a region of interest (ROI, ~16 pixels) in the background to an ROI in the corpus callosum before and after slice tilting and intensity compensation.

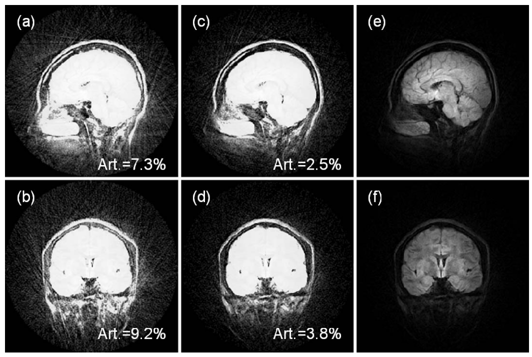

Figure 2: Sagittal (Top) and Coronal (bottom) DW images: (a-b) without tilt, with window and level adjusted to view artifacts; (c-d) Results of applying a tilt of 2° and the post-processing step; (e-f) The images from (c) and (d) at standard window and level settings.

Results Figure 2 illustrates the performance of the proposed technique for sagittal (top row) and coronal (bottom row) DW images. Figures 2a-d are displayed with window and level settings that highlight the streaking artifacts. The strength of the artifacts decreased from 7.3% (Fig. 2a) and 9.2% (Fig. 2b) before the tilt, to 2.5% (Fig. 2c) and 3.8% (Fig. 2d) after applying the tilt of 2° and the signal intensity correction. The images after artifact reduction (Figs. 2c-d) are also displayed with standard window and level settings in Figs. 2e-f.

Discussion We have demonstrated that a small tilt applied to each blade of the PROPELLER sequence, followed by a signal intensity correction, has noticeably reduced the streaking artifacts in non-axial diffusion images. A drawback of using a constant tilt angle in the current implementation is that the signal intensity of all PROPELLER blades is affected irrespective of their relative contributions to the artifacts, which is most likely responsible for the "center brightening" effect observed in Figs. 2e-f. This problem is expected to be reduced by using a variable tilt angle scheme in which the optimal tilt angle is determined based on the blade orientation.

Conclusions A simple slice tilting technique has noticeably decreased streaking artifacts in non-axial DW images using an FSE-based PROPELLER sequence. With further optimizations, this technique is expected to allow high quality DW images to be obtained in arbitrary plane orientations.

References (1) Weisskoff RM, *et al.*, MRM, 1993, 29: 796-803 (2) Du Y, *et al.*, MRM, 2002, 48: 509-515 (3) Pipe JG, MRM, 1999, 42: 963-939. (4) Pipe JG, *et al.*, MRM, 2002, 47: 42-52. (5) Deng J, *et al.*, MRM, 2008, 59: 947-953.