Reduced eddy current induced artifact in 7T single shot diffusion weighted echo planar imaging

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INTRODUCTION Diffusion-weighted imaging (DWI) is a non-invasive MRI technique for *in-vivo* measurement of the diffusion of water molecules (1). Theoretical background of DWI was established by Stejskal and Tanner (2). The pulse sequence consists of two diffusion gradient blocks positioned around an 180° refocusing pulse. At the present time, single-shot echo planar imaging (EPI) (3) is the most widely used spatial encoding scheme for diffusion imaging. Compared to conventional imaging sequences EPI is more prone to a variety of artifacts such as N/2 (or Nyquist) ghosting resulting from phase errors that alternate between odd and even echoes. Reference scan methods are most commonly used for N/2 ghosting artifact correction. Inconsistent phase errors between odd and even echoes in the echo train are measured by navigator echoes (a reference scan) which is typically located between the 90° excitation pulse and the diffusion gradient (4, 5). DWI sequences based on single-shot EPI, however, has an additional source of N/2 ghosting artifacts that are associated with B_0 field perturbations resulting from diffusion gradient-induced eddy currents (6). Hence, diffusion gradient-induced phase error must be considered in DWI. In this study, we investigate the impact of navigator echo acquisition locations. Our proposed navigator echo acquisition scheme, which acquires it following the pair of diffusion gradients, shows 41% reduced N/2 ghost signal in phantom results and qualitatively reduced N/2 ghost artifact in *in-vivo*. In addition, the effect of a dummy diffusion gradient is investigated as an alternative method reduces eddy current.

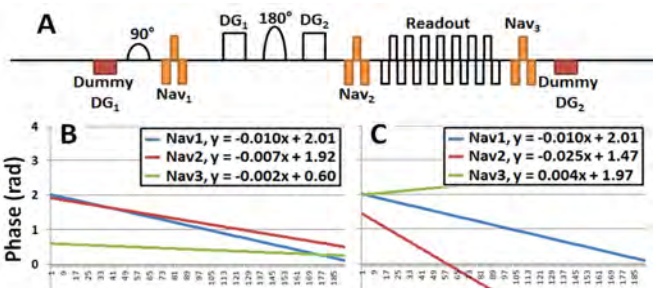

Figure 1. (A) Proposed sequence diffusion sequence diagram, Phase evolution in the navigator echoes from (B) b=0 and (C) b=1000 s/mm^2

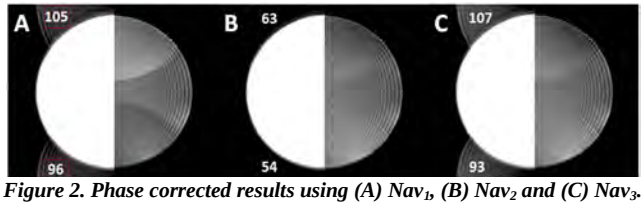

Figure 2. Phase corrected results using (A) Nav$_1$, (B) Nav$_2$ and (C) Nav$_3$. left half area is displayed with enhanced signal. Background ghost signals (mean) were displayed with images. Regriding process was not performed.

METHODS Phantom and *in-vivo* (IRB-approved) data were acquired on a 7T MRI scanner with SC72 gradients (MAGNETOM, Siemens) using a 32-channel phased array head coil (Nova Medical). The DWI sequence diagram is shown in Fig. 1A. Additional set of dummy diffusion gradients (Dummy DG_1 and Dummy DG_2, same duration with DG_1 and DG_2) and navigator echoes (Nav_2 and Nav_3) are added to explorer the behavior of diffusion gradient-induced eddy current and ghosting artifact. MRI data acquisitions in phantom and *in-vivo* were conducted as follows: TR/TE = 5000/62 ms, 15 slices, 2.0 mm^3 isotropic resolution, 30 DW-directions with b = 1000 s/mm^2, a b = 0 volume and 6/8 partial k-space in k_y direction. The DWI data were corrected for N/2 ghost artifact using three different sets of navigator echoes (4, 5). The processed apparent diffusion coefficient (ADC) maps and fractional anisotropy (FA) maps were reconstructed by MedINRIA (http://www-sop.inria.fr).

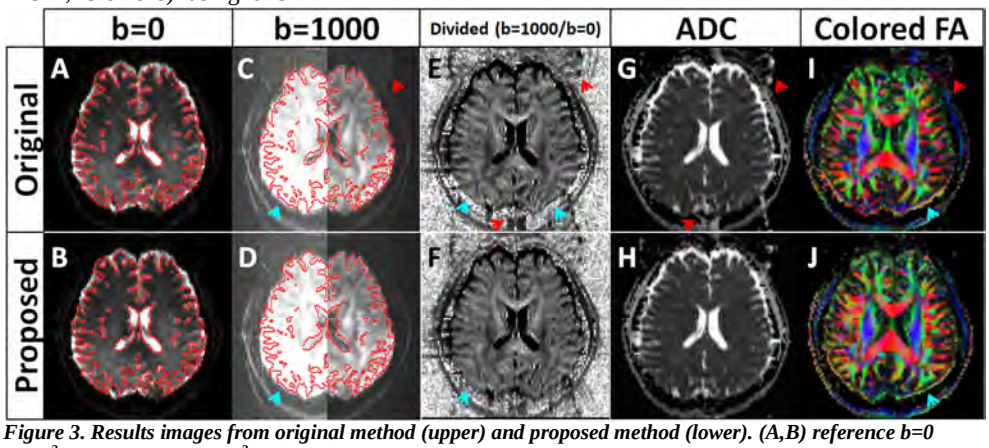

Figure 3. Results images from original method (upper) and proposed method (lower). (A,B) reference b=0 s/mm^2, (C,D) b=1000 s/mm^2, left half area is displayed with enhanced signal, (E,F) divided, (G,H) ADC and (I,J) color coded FA. Segmented tissue border line is shown with red lines to compare the results in A-D.

RESULTS Typical eddy current effects are shown in Fig. 1B and C. In the absence of diffusion gradients (Fig. 1B), phase evolution during readout from Nav_1 and Nav_2 doesn't show much difference. However, in the presence of diffusion gradients (Fig. 1C; 1000 s/mm^2), Nav_1 and Nav_2 show a clear shift resulting from eddy currents. Figure 2 shows the results of N/2 ghost phase correction using three different navigator echoes. Compared to the original correction method (Fig. 2A, Nav_1 was used) our proposed method (Fig. 2B; Nav_2 was used) shows 41% reduced N/2 ghost signal in the background area. In this phantom experiment dummy diffusion gradients were not applied. Figure 3 compares *in-vivo* results from original method (upper row; Nav_1 was used and absence of dummy diffusion gradient) and proposed method (lower row; Nav_2 was used and presence of dummy diffusion gradient). Compared to the original method, our proposed method reveals qualitatively reduced N/2 ghost artifact (indicated by red arrows). The beneficial effect of the presence of the dummy diffusion gradients also can be seen. To compare results, segmented tissue border line based on the reference b=0 image is overlaid on Fig. 3C and D. As shown, the image shifting induced by B_0 field perturbations resulting from eddy currents is reduced in the results (Fig. 3D, F and J; pointed by blue arrows).

DISCUSSION and CONCLUSION In this work, a novel method that reduces eddy current-induced N/2 ghost artifacts and image shifts in single shot DW-EPI has been presented. The differences between phase evolution of Nav_2 in Fig. 1B and C, reflect the additional presence of eddy currents which are induced by diffusion gradients. It has been suggested that navigator echoes that include a similar amount of phase evolution (= Nav_2) with DW-EPI echo train can reduce N/2 ghost artifact. Compared to the original method, the new method (add dummy diffusion gradients and phase correction using Nav_2) shows reduced N/2 ghosting signal as well as image shift artifact. In current method, due to incomplete knowledge of the diffusion gradient induced eddy current the moment of dummy diffusion gradient (= 0.5×DG, same polarity with original diffusion gradient) is empirically determined. The behavior and effect of dummy diffusion gradients needs further investigation. If confirmed, it may provide improved image quality in DW-EPI. In conclusion, the potentials of the newly proposed method have been discussed and examples of the improved 7T DWI results are demonstrated.

References: [1] Wesbey, 1984, Invest Radiol 19:484 [2] JE. Tanner and Stejskal, 1965, J. Chem. Phys. 42:288 [3] Turner, 1990, Radiology 177:407 [4] Bruder, 1992, MRM, 23:311 [5] Schmitt, 1998, springer [6] Calamante, 1999, MRM, 41:95