Turbo Z-Shimmed UNFOLD EPI

G. Wu[1], and S-J. Li[1]

[1]Department of Biophysics, Medical College of Wisconsin, Milwaukee, Wisconsin, United States

INTRODUCTION The gradient-recalled echo-planar imaging (EPI) technique is sensitive to the bulk susceptibility differences between tissue and air or bone in the inferior part of the human brain. The susceptibility differences induce severe static field inhomogeneities and result in two major artifacts: image distortion and signal dropout. Studies related to reduction of susceptibility-induced artifacts have been intensive, while most of them only attacked one of the two major artifacts. To simultaneously reduce both the artifacts for fMRI, pulse sequences incorporating the z-shim method into the multi-segmented EPI imaging techniques have been proposed (1, 2). However, one drawback for these pulse sequences is that the spatial coverage is limited. In this study, we propose a turbo z-shimmed UNFOLD EPI sequence (TZ-UNFOLD EPI) to increase the spatial coverage of the turbo-segmented z-shim EPI sequence (2) so that whole-brain fMRI with reduced susceptibility-induced artifacts is feasible. This sequence employs the UNFOLD (UNaliasing by Fourier-encoding the Overlaps using the temporaL Dimension) technique (3) and the selective z-shim strategy (4) to achieve a whole-brain spatial coverage for fMRI.

METHODS The UNFOLD technique is used with a reduction factor of 2, and two half k-spaces (all even lines and odd lines, respectively) are acquired alternatively along the temporal dimension. The reconstructed images can be unaliased using temporal low-pass filtering with a cut-off frequency of half of the Nyquist frequency (3). The regions with severe field inhomogeneities are located only in the inferior part of the human brain. Along the axial orientation, only about half of the brain needs z-shim compensation. Figure 1 shows the schematic diagram of the TZ-UNFOLD sequence. When the z-shim compensation is needed, one slice image could be obtained from the two z-shimmed images (I and II) with two continuous RF excitations to this slice. The flip angles of these two RF pulses are 45° and 90°, respectively (5). The z-shim compensation gradient for Image I is 0 to reserve the bulk image intensity and for Image II is determined with the method proposed in ref. (2). Images I and II are combined by computing the square root of the sum of their squares to generate the final image for one slice (Z-Slice). When the z-shim is not needed, these two RF pulses both with a flip angle of 90° excite two different slices and generate two images for these two slices (NZ-Slices I and II), respectively.

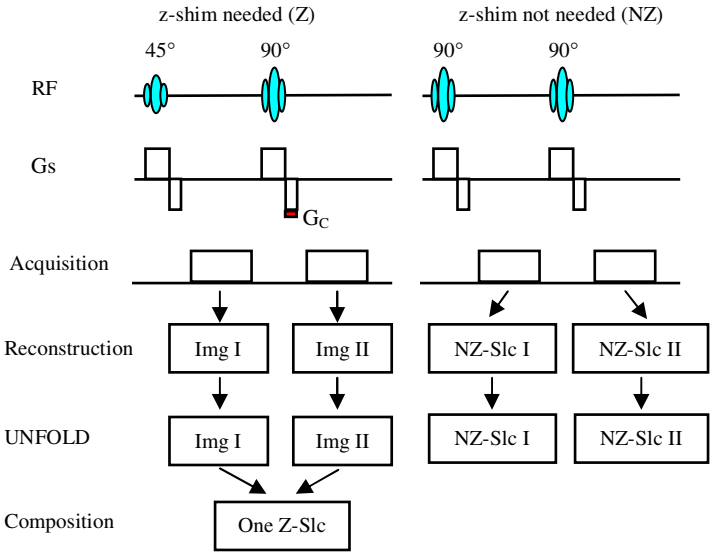

Fig. 1 Schematic diagram of the TZ-UNFOLD EPI sequence. Gc is the z-shim gradient as modification to the slice refocusing gradient.

The TZ-UNFOLD EPI sequence was implemented on a GE Signa EXCITE 3T system. Four healthy subjects were recruited and experiments were preformed as a part of a protocol approved by the Institutional Review Board at the Medical College of Wisconsin. The imaging parameters were FOV = 24 cm, matrix = 64×64, bandwidth = ±62.5 kHz, TR = 2 s, TE = 25 ms, slice thickness = 4 mm, and slice orientation = axial. The number of z-shim needed slices was set as 16, and the total number of slices was 30, which ensured the whole-brain coverage. The cut frequency of the low-pass filter for UNFOLD is 0.125 Hz. A finger-tapping fMRI experiment was conducted. The finger-tapping paradigm was 380s long, initially with 60s resting followed by four epochs of 20s on and 30s off and then 30s resting. Deconvolution analysis with a duration time of impulse hemodynamic response of 12 s was used to detect the fMRI activation maps. For comparison, the same experiment was also conducted using a conventional single-shot EPI (SS EPI) pulse sequence with the same imaging parameters as mentioned above (except that TE = 27 ms and flip angle = 90°).

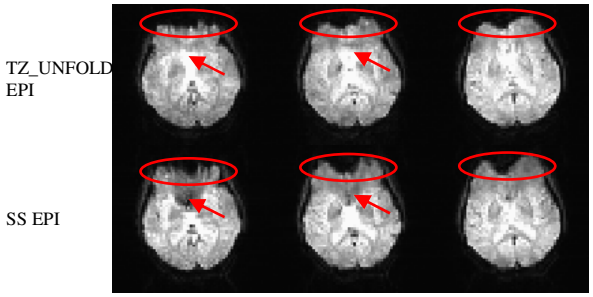

Fig. 2 Comparison of image distortion and signal dropout between TZ-UNFOLD and SS EPI

RESULTS Figure 2 shows the image quality comparison between TZ-UNFOLD EPI and SS EPI. Clearly, image distortion (indicated by ellipses) and signal dropout (indicated by arrows) were greatly reduced with the TZ-UNFOLD EPI sequence. Figure 3 shows representative finger-tapping activation maps obtained with TZ-UNFOLD EPI and SS EPI. The significant activation was determined with an F-value threshold of 6.87 ($p<10^{-6}$). The color represents the signal percentage change induced by the finger-tapping task in the activated region. The fMRI results are comparable between TZ-UNFOLD EPI and SS EPI.

DISCUSSION Due to the partial excitation and k-space acquisition, the spatial signal-to-noise ratio (SNR) with the proposed TZ-UNFOLD EPI sequence is about 50%~70% of that with the SS EPI sequence. This is a compromise for the TZ-UNFOLD EPI in reducing the image distortion and signal dropout simultaneously while achieving high spatial coverage. However, in fMRI, temporal SNR is more essential to activation detection. The dominance of physiological noise over thermal noise in fMRI at 3T or higher field benefits the TZ-UNFOLD EPI temporal SNR, compared to its spatial SNR. The physiological noise level is about twice of the thermal noise when acquired using a single-shot sequence with typical imaging parameters at 3T (6). According to our simulation, the TZ-UNFOLD EPI temporal SNR can be about 86% of the SS EPI temporal SNR, assuming the TZ-UNFOLD spatial SNR is 60% of the SS EPI spatial SNR. This indicates that the proposed TZ-UNFOLD EPI is suitable to fMRI studies at 3T or higher field. In conclusion, we have developed a turbo z-shimmed UNFOLD EPI pulse sequence. This sequence can simultaneously reduce the image distortion and signal dropout artifacts induced by the susceptibility effects, and achieve whole-brain coverage for fMRI with typical imaging parameter settings. The TZ-UNFOLD EPI could be a solution to susceptibility-effect reduction in ultra-high field for fMRI.

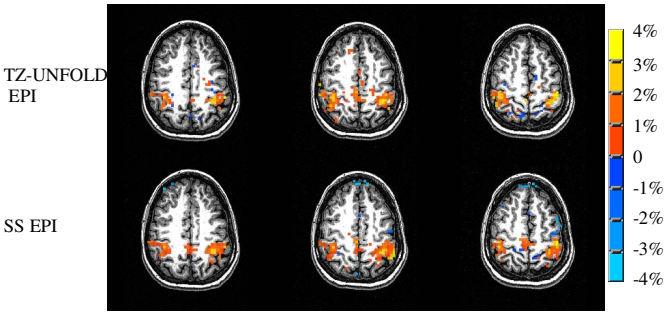

Fig. 3 Comparison of finger-tapping activation maps between TZ-UNFOLD and SS EPI

REFERENCES **1.** Li Z *et al*, *MRM*, 48:312-321, 2002; **2.** Wu G and Li S-J, *ISMRM* 2007, p3310; **3.** Madore B *et al*, *MRM*, 42:813-828, 1999; **4**. Du Y *et al*, *MRM*, 57:396-404, 2007; **5**. Wang D, *et al*. *ISMRM* 2005, p2409; **6**. Kruger G and Glover GH, *MRM*, 46:631-637, 2001.

ACKNOWLEDGEMENTS This work was supported by NIH Grants DA10214, EB01820, and AG20279.