# Internal Reference Scans for Artifact Correction in Multi-Shot Segmented EPI Acquisition

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

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

## INTRODUCTION

Multi-shot segmented imaging is subjected to ghost artifacts arising from the amplitude and phase discrepancies between segments. A navigator echo method, which acquires extra data points preceding each segment acquisition, has been proposed to reduce such artifacts (1). The navigator echo method is based on an assumption that the amplitude differences detected with the navigator echo method can be used to correct the amplitude discrepancies. However, in the case of the turbo segmented imaging (TSI), the navigator echo method may not be the sufficient way to correct the ghost artifacts. Since the TSI sequence uses multiple-variable flip angle and consecutive excitations to fill the segmented k-space in order to reduce the motion artifact (2), different T1 recoveries of acquired signal components may occur during each segment acquisition and could result in different longitudinal magnetization in composition. Further, their differences in T2* decay are not reflected by the navigator echoes. Therefore the amplitude differences detected with the navigator echo method could not reflect the amplitude discrepancies at echo time. To improve the navigator echo method for the reduction of ghost artifacts, the acquisition of extra reference lines at the k-space center is proposed to detect the amplitude differences between segments. This method is implemented with a gradient-echo EPI sequence using the TSI technique and is termed TS-EPI. This method can be applied to general multi-shot segmented imaging sequences for the reduction of ghost artifacts.

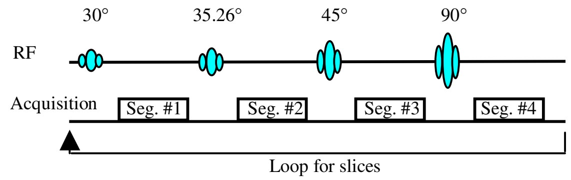


**Fig. 1.** Schematic diagram of the TS-EPI sequence with four segments

## METHODS

Fig. 1 shows the schematic diagram of the TS-EPI sequence with four segments. The four segments are acquired sequentially to form a slice image. The flip angles are calculated according to $tan(\theta_n) = sin(\theta_{n+1})$, where n is the index of segments and the flip angle of the last segment is 90°, given in Ref. 2, to ensure equal signal for each segment, assuming the magnetization recovery is negligible. An echo time shift method (3) is incorporated to achieve smooth T2* decay and phase accumulation in the phase encoding direction, and a spoiling gradient along the slice selection direction is applied to each segment to prevent the formation of stimulation echoes. The within-segment ghosting artifacts arising from the inconsistency between the odd and even echoes are corrected with the reference data acquired from a pair of zero phase encoding echoes (4). Fig. 2 shows the phase encoding strategy for the proposed between-segment artifact reduction method, combined with the within-segment artifact reduction method. Lines A, B, and C represent the corresponding readout k-space lines. Lines B and C are two extra reference k-space lines with zero phase encoding. Because the Prephase marked with cyan varies with different segments, line A has different phase encodings and cannot be used for between-segment artifact correction. The blips marked as red are added to make line B zero phase encoding for all the segments, and then the next blips are skipped so that line C has the same phase encoding as line B. With this phase encoding strategy, lines B and C can be used for both within- and between-segment artifact corrections. The blips marked as blue have bigger area than the regular blips to ensure the following k-space lines are properly encoded. The TS-EPI sequence was implemented on a GE Signa EXCITE 3T system. The acquisition parameters were FOV of 24 cm, matrix of 64×64 and 128×128, bandwidth of 125 kHz, TR of 2 s, number of image repetition were 60, TE of 10 ms and 30 ms, slice thickness of 4 mm with axial orientation. A standard single-shot EPI (SS-EPI) pulse sequence was used for comparison.

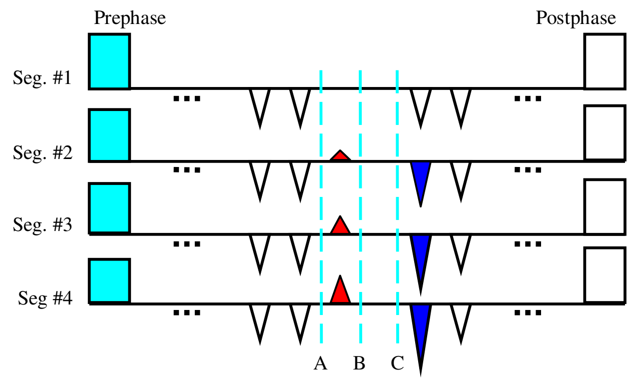


**Fig. 2**. Phase encoding strategy for artifact correction.

## RESULTS AND DISCUSSION

Fig. 3 compares the image qualities obtained with a four-segmented TS-EPI sequence and an SS-EPI sequence. Compared with the SS-EPI 64x64 images, the TS-EPI images have less distortion, even with a matrix size of 128x128. Based on the RF flip angles applied for each segment, the SNR of TS-EPI images should be one half of that of SS-EPI images under the same parameters of TR, TE and matrix size. By taking into account the magnetization recovery among segments, the measured SNR of TS-EPI images was higher, which can be seen from the second and fourth rows in Fig. 3. The TS-EPI images with a TE of 10 ms have much less signal dropout in the orbitofrontal cortex region. In conclusion, a within- and between-segment artifact correction scheme was proposed and implemented in the TS-EPI sequence. The method can be readily used to the conventional multi-shot segmented acquisitions. This TS-EPI sequence could be used to obtain high spatial and temporal resolution images with minimal motion artifacts for BOLD and ASL perfusion fMRI studies

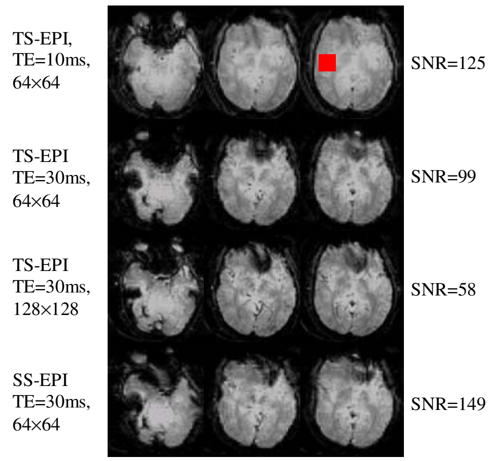


**Fig. 3.** Comparison of gradient-echo images acquired with TS-EPI and SS-EPI. The signal-to-noise ratio (SNR) was calculated from the averaged intensity in the red box divided by the temporal standard deviation from the background region.

## REFERENCES

**1.** Hu X and Kim SG. *MRM*, 31:495-503, 1994; **2.** Wang D, et al. *Proc ISMRM 14th Meeting* 2005, p2409; **3.** Feinberg DA and Oshio K. *MRM*, 32:535–539, 1994; **4.** Jesmanowicz A et al, *Proc SMRM 12th Meeting* 1993, p 1239.

## ACKNOWLEDGEMENTS

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