# Flow Compensation in Frequency-encode Direction for the Fast Spin Echo Triple-Echo Dixon (FTED) Sequence

**K. Shi[1,2], R. Low[3], S. Bao[1], and J. Ma[2]**
[1]Beijing City Key Lab of Medical Physics and Engineering, Beijing University, Beijing, China, People's Republic of, [2]Imaging Physics, University of Texas MD Anderson Cancer Center, Houston, Texas, United States, [3]Sharp and Children's MRI Center, San Diego, CA, United States

**Introduction:** Fast spin echo (FSE) triple-echo Dixon (FTED) sequence [1] is an FSE implementation of the Dixon technique [2] that permits robust water and fat separation from data acquired in a single scan. Preliminary studies have shown that FTED can be used for routine clinical fat suppressed T2-weighted imaging of head and neck [3] and of the abdomen [4]. Because FTED uses three consecutive readout gradients of alternating polarity, flow compensation with gradient moment nulling [5] along the readout axis is difficult to achieve. In this work, we investigated the 1st order moment of the readout gradients in FTED and proposed two different strategies to minimize the gradient moments from the triple echo readout. The effectiveness of these methods in reducing the flow-induced artifacts in FTED was demonstrated in a phantom experiment.

**Experiments and Method:** Since both stimulated echo (STE) and spin echo (SE) components are present in FTED and experience the gradients differently, the 1st order gradient moment (GM) for the two signal components is not the same and generally non-zero (Fig. 1a). However, the GM at the 1st and the 3rd echo center position stays the same within each echo spacing period (ESP) due to the symmetry of the FTED readout gradients. Starting at the 1st ESP for SE and 2nd ESP for STE, the GM is also the same for each signal component for the corresponding echoes within every other ESP (e.g., the 1st echo center within the 2nd and the 4th ESP). The 1st method we propose for FTED flow compensation is to null the GM at every RF location so that the Carr-Purcell-Meiboom-Gill condition is maintained and SE and STE signals are in-phase. This is achieved by inserting a pair of gradients immediately before and after the FTED readout gradients, as shown in Fig. 1b. The area of the GMN gradients is combined with the area of the dephasing gradient in the original FTED to ensure 0th order GM balance. For the 2nd method, we insert a pair of gradients before and after the FTED readout and an additional bipolar gradient before the first 180° pulse in order to minimize the GM of only the SE component of the signal. Although the GM is not nulled at the RF locations in the 2nd method, complete nulling of the GM for the SE component of the signal is achieved at the 1st and 3rd echo locations during all ESP periods. Further, the GM for the SE component at the center echo location and for the STE component is in general minimized (Fig. 1c). In order to evaluate the efficacy of the proposed methods, we implemented both modifications to the FTED pulse sequence and imaged a phantom containing both water and fat. The imaging FOV also included a tube that was connected to a water pump with a flow rate of approximately 10mm/s. We performed all the experiments on a GE 1.5T whole body MRI scanner and using an 8-channel phased array head coil. The following scan parameters were used: FOV 24x24cm, slice thickness 4mm, echo train length 16, TE 85ms, TR 4000ms. Scan time for each acquisition was 56 seconds.

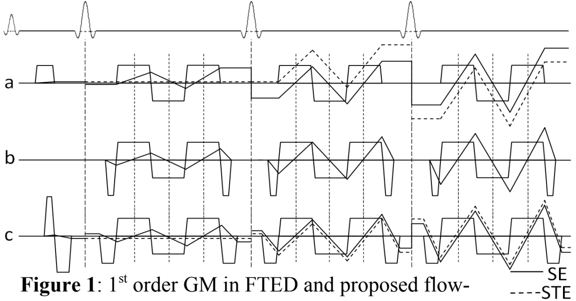

**Figure 1**: 1st order GM in FTED and proposed flow-compensation methods (a) FTED (b) nulling at RF position; (c) nulling SE at echo center.

| | Signal component | GM in 2nd ESP (in units of $\pi$) | | GM in 3rd ESP (in units of $\pi$) | |
|---|---|---|---|---|---|
| | | 1st echo | 2nd echo | 1st echo | 2nd echo |
| FTED | SE | 0.001 | -0.013 | 0.054 | -0.041 |
| | STE | 0.170 | 0.157 | 0.115 | 0.128 |
| Method 1 | SE | 0.010 | -0.002 | 0.009 | -0.002 |
| | STE | 0.008 | -0.003 | 0.010 | -0.002 |
| Method 2 | SE | 0.001 | -0.011 | 0.001 | -0.014 |
| | STE | -0.074 | -0.086 | 0.064 | -0.061 |

**Table 1**: 1st order GM for FTED and two proposed flow-compensation methods

**Results:** The 1st order GM for the STE and SE component of original FTED and two proposed methods were calculated for the scan parameters used for the phantom experiment (Table 1). Only the 1st and 2nd echo in the 2nd and 3rd ESP periods is listed because of the periodicity of the GM for different echoes or different ESPs (e.g., the GM during the 2nd ESP and the 4th ESP is the same for corresponding echoes). In comparison to the original FTED, the overall GM (summed over all different ESPs) by Method 1 is reduced to 27.2% for SE and 5.4% for STE, respectively. Similarly, the overall GM by Method 2 is reduced to 18.9% for SE and 51.5% for STE. The phantom images in Figure 2 show that the ghosting artifacts from the flowing water in the original FTED are effectively reduced by both Method 1 and Method 2.

**Discussions:** The triple echo readout in the original FTED sequence places a relatively strict demand on the gradient timing. As a result, complete nulling for all echo components and at different time points is difficult to achieve without significantly impacting the ESP. In our implementation, the modification of the gradient waveforms in Method 1 and Method 2 increased ESP to11, 184 us and 12, 512us, respectively (from an ESP of 10,968 us for the original FTED). In comparison, flow compensation used in conventional FSE sequence increases the ESP to 7,328us from 6,592us using the same scan parameters. Therefore, the ESP increase from flow-compensation is comparable for different methods and is not expected to cause any substantial image quality compromise.

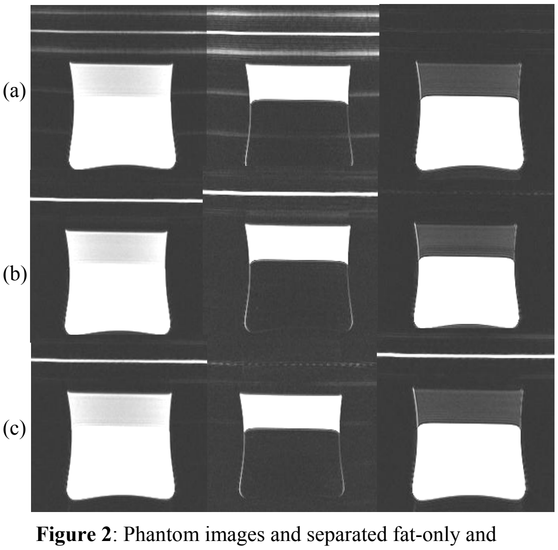

**Figure 2**: Phantom images and separated fat-only and water-only images for (a) FTED, (b) nulling at RF, (c) nulling at the echo center. Flow-artifacts are effectively reduced in (b) and (c). Note that water tube in (a) and (b) was incorrectly separated into the fat-only image because the existing region growing algorithm cannot handle disconnected objects.

**Acknowledgements:** One of the authors (K.S.) was supported by China Scholarship Foundation and China National Natural Science Foundation (No. 60672104).

**References:** [1]. Ma J, et al, MRM 2007;58(1):103-109. [2]. Dixon WT. Radiology 1984;153(1):189-194. [3]. Ma J,et al, AJNR 2009;30(1):42-45. [4]. Low RN,et al, JMRI 2009;30:569-577. [5]. Hinks RS,et al, MRM 1994;32(6):698-706.