An Extended Fast Spin-Echo Triple-Echo Dixon Technique with Flexible Echo Separations

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Introduction

Fast spin-echo triple-echo Dixon (FTED) sequence uses a set of three fast switching bipolar readout gradients during each echo spacing period of fast spin echo (FSE) to produce three images in a single acquisition.[1] The middle echo is placed at the center of the FSE echo spacing and thus has water and fat signals in-phase. In the original implementation, the first and the third echo are placed symmetrically around the middle echo to have water and fat signals approximately 180° out-of-phase. Because of this requirement, the minimum echo spacing of FSE is fixed. Further, scan parameters such as the frequency encode steps and receiver bandwidth may not be flexible. In this work, we propose an extended FTED acquisition so that the echo separation between the three readout gradients in FTED is flexible. The advantages of the extended FTED are that FSE echo spacing can be minimized without any deadtime and scan parameters are more adjustable. We use a flexible echo time two-point Dixon water and fat separation algorithm for postprocessing the extended FTED images from the first and third echo readout with a flexible water and fat relative phase. Using the proposed technique, we demonstrate that T2-weighted images of the entire liver can be acquired within a single breath-hold.

Method

Fig. 1 represents the pulse-sequence diagram of the extended FTED sequence. For an arbitrary echo separation τ, the three images acquired can be expressed as:

$\mathrm{S}_- = \left(W + Fe^{-i\theta}\right)e^{i(\phi_0 - \phi_-)}$; $\quad \mathrm{S} = (W + F)e^{i\phi_0}$; $\quad \mathrm{S}_+ = \left(W + Fe^{i\theta}\right)e^{i(\phi_0 + \phi_+)}$;

where W and F represent magnitudes of water and fat signals, respectively. ϕ_0 is phase-error of S. ϕ_- and ϕ_+ are the non-chemical shift related phases that are accumulated between the 1st and the 2nd echo-separation and between the 2nd and the 3rd echo-separation, respectively. θ is the chemical-shift related phase of fat that depends on τ and may account for multiple fat spectral contributions. After ϕ_0 is determined from S and removed from all three images, W and F separation only requires determining $e^{i\phi_-}$ and $e^{i\phi_+}$. Mathematically, this process is equivalent to finding the correct vector solution from two possible vector candidates from the first pair of images and another vector solution from two other possible vector candidates for each.[2-4] In this work, we used a region-growing based two-point flexible echo time Dixon phase-correction algorithm[4,5] to estimate $e^{i\phi_-}$ and $e^{i\phi_+}$ and to yield three phase-corrected images:

$\mathrm{S'}_- = \mathrm{S}_- e^{-i(\phi_0 - \phi_-)} = W_1 + F_1 e^{-i\theta}$; $\quad \mathrm{S'} = Se^{-i\phi_0} = W_1 + F_1 = W_2 + F_2$; $\quad \mathrm{S'}_+ = \mathrm{S}_+ e^{-i(\phi_0 + \phi_+)} = W_2 + F_2 e^{i\theta}$;

Afterwards, two pairs of water-only images (W_1 and W_2) and fat-only images (F_1 and F_2) images are averaged to produce the final output images.

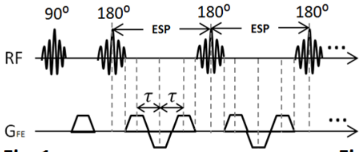

Fig. 1

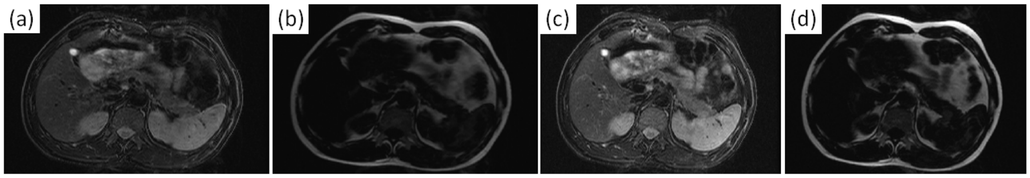

Fig. 2

Experiment and Results

The extended FTED pulse sequence was implemented on a GE 1.5T whole-body scanner and in vivo T2-weighted abdomen images were acquired using an 8-channel torso phased array coil and the following scan parameters: τ = 1.688ms (corresponding to an approximate water and fat relative phase angle θ of 117^0), TR/TE = 2500ms/82.72ms, ETL = 16, echo spacing = 8272ms, acquisition matrix = 256 x 160, FOV = 36cm x 25.2cm, RBW = ±83.33kHz, and slice-thickness/slice-gap = 6/1mm. For comparison, the original FTED images were acquired using otherwise identical scan parameters except for τ = 2.16ms, RBW = ±62.5kHz, and ESP = 9628ms. The proposed postprocessing algorithm was implemented in MATLAB (MathWorks) and used to produce final water-only and fat-only images. Fig. 2 (a) and (b) are the water-only and fat-only images using data acquired by the original FTED sequence. Fig. 2 (c) and (d) show the corresponding water-only and fat-only images by the extended FTED sequence. Uniform water and fat separation was observed in both cases. However, the extended FTED allowed more flexible acquisition. As a result of the reduced echo separation, a total of 17 slices were acquired by the extended FTED as opposed to a total of 15 slices by the original FTED in a same single breath-hold of 25 seconds even without parallel imaging.

Discussion

Fat suppressed FSE images are widely used for T2-weighted or T1-weighted sequences in routine clinical studies. Fat suppression by conventional chemical shift selective saturation technique may not be always reliable and often produce sub-optimal images. The FTED sequence offers an alternative that can overcome the difficulty. The extended FTED sequence presented here allows more flexibility in acquisition. With reduced echo separation and reduced FSE echo spacing, the extended FTED offers increased scan efficiency and better image quality. The technique is therefore expected to be useful in several important clinical applications.

References: [1] Ma J, et. al., MRM 2007;58(1):103-109. [2] Xiang QS. MRM 2006;56(3):572-584. [3] Berglund J, et al. MRM 2011:65(4):994. [4] Ma J. ISMRM 2011. p. 2707. [5] Ma J, et. al., ISMRM 2013. p.2414.