A fast spin echo triple echo Dixon (fTED) technique for efficient T2-weighted water and fat imaging

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Introduction

Previously-published fast spin echo (FSE)–based Dixon techniques for water and fat separation all require multiple scans [1-3]. Further, the echo spacing (esp) time between the two successive refocusing RF pulses often needs to be increased to effect the phase shift between the water and fat signals as necessitated in a Dixon technique [1,3]. Consequently, the FSE scan efficiency is reduced and additional image blurring may occur [2]. Although asymmetric echoes can be used to minimize the increase in esp, multiple scans are still required and partial k-space image reconstruction is necessary [2].

In this work, we developed a novel fast spin echo triple echo Dixon (fTED) technique which acquires three raw images in a single scan with readout gradients of alternating polarity. The three raw images are then used to generate separate water-only and fat-only images for each slice. In comparison to other FSE-based Dixon techniques, the fTED technique requires only a single scan and practically no increase in esp. We demonstrate that for the same imaging parameters, T2-weighted water-only and fat-only images of an entire abdomen can be collected by using the fTED technique in the same scan efficiency as by the conventional FSE technique.

Methods

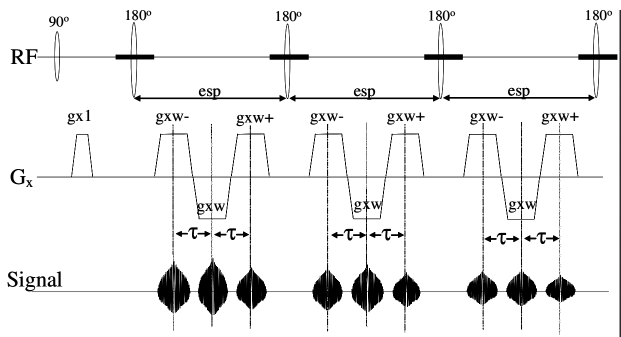

Fig. 1. The pulse sequence diagram for the proposed fast spin echo triple echo Dixon (fTED) technique.

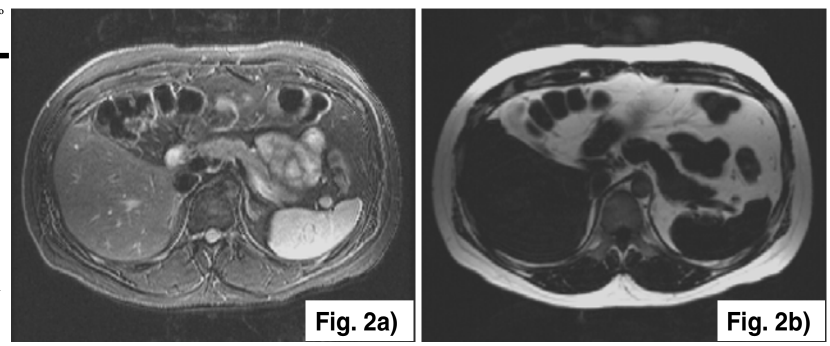

Fig. 2. The breath hold water-only (a) and fat-only (b) images generated by the fTED technique. With a 256x192 acquisition matrix, an entire abdomen can be covered in two breath holds.

Fig. 1 presents the pulse sequence diagram of the proposed fTED technique. It is identical to the FSE pulse sequence, except that a single readout gradient during each esp-time period in conventional FSE is replaced with three readout gradients (gxw-, gxw, and gxw+) of alternating polarity. The time-delay between the three readout gradients, denoted τ in Fig. 1, is set to approximately 2.3ms. The total readout time is kept equivalent to the time of a single readout by using correspondingly higher receiver bandwidths for the same scanning parameters. Ignoring the small relaxation effects during τ, the three raw images that correspond to gxw-, gxw, and gxw+ can be expressed as follows [4]:

$$S_- = (W - F)e^{i(\phi_o - \phi)}; \qquad S = (W + F)e^{i\phi_o}; \qquad S_+ = (W - F)e^{i(\phi_o + \phi)}$$

where W and F represent relaxation-weighted water and fat signals, respectively. ϕ_0 and ϕ are the τ–independent and τ-dependent phase shifts, respectively. Separation of W and F can be achieved after the determination of $e^{i\phi_o}$ and $e^{i\phi}$. Here, $e^{i\phi_o}$ can be easily determined from S. Since S- and S+ have the same functional form as the opposed-phase signal acquired in a dual echo Dixon technique, the same phase correction algorithm in the dual echo Dixon technique can be used to determine $e^{i\phi}$ [5].

The fTED pulse sequence was implemented on a GE 1.5 T whole body scanner operating under the EXCITE HD platform and was used along with an 8-channel torso phased array coil to acquire abdomen images of a volunteer. The image reconstruction algorithm for fTED was implemented in Matlab, and image reconstruction was automatic without any user interventions.

Results

Fig. 2a-b) show the water-only and fat-only images of a representative slice. With the following parameters (TR/TE = 2500/85ms, echo train length = 19, acquisition matrix= 256x192, FOV= 36cm, receiver bandwidth = ±62.5kHz, slice thickness/gap = 6/1mm), a total of 22 slices were acquired in only two breadth holds of 25 seconds. This scan efficiency is the same as the conventional FSE with chemical shift selective fat saturation and otherwise identical scan parameters. However, the fat suppression was much more uniform and consistent for all the slices in the fTED images than in the conventional FSE images (not shown here).

Conclusions

By replacing the single readout gradient with three readout gradients of alternating polarity in FSE, three raw images with water and fat either in-phase or 180^o out-of-phase can be acquired in a single scan for maximum data acquisition efficiency. A conventional spin echo implementation of a similar approach has been reported at much lower field strength [6]. Here, we demonstrated that the three raw images acquired with FSE and at 1.5 Tesla can be used readily to generate separate water-only and fat-only images. Compared to the previous implementation of other FSE-based Dixon techniques, the new fTED technique does not require multiple scans or increase in esp. For the same imaging parameters, fTED achieves the scan efficiency of the conventional FSE, yet much more uniform and consistent image quality.

References

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