T1-Contrast Enhanced Single-Point Dixon With Integrated PSIR Based on Orthogonal Phase

J. Son[1], and J. Ji[1]

[1]Electrical & Computer Engineering, Texas A&M University, College Station, TX, United States

Introduction

Phase-Sensitive Inversion Recovery (PSIR) can enhance T1-contrast and has been widely used for clinical applications such as detection of myocardial infarction using gadolinium-delayed hyperenhancement, and evaluation of pulmonary blood flow [1]. PSIR images often contain undesirable strong fat signals. Fat suppression using multi-point Dixon techniques uses phase information to separate fat signals from water signals, which has several advantages over SPECIAL (SPECtral Inversion At Lipid) and CHESS (CHEmical Shift Selective saturation) including improved SNR and robustness against field inhomogeneity [2]. However, Dixon techniques in general are not comparable with PSIR because both need to identify 180^o phase difference due to water/fat chemical shift or spin polarity. In this research, we developed a new pulse sequence and reconstruction method to integrate PSIR with a single-point Dixon technique for water/fat imaging with improved T1 contrast. The unique feature of this technique is that it induces and utilizes orthogonal phase shifts by chemical shift and inversion recovery.

Methods

Fig. 1 illustrates the 'Contrast-enhanced Dixon pulse sequence' and corresponding displacement of fat and contrast-enhanced water spins on the rotating frame. After an inversion RF pulse is applied, longitudinal magnetizations of fat and water spins are recovered at different rates, governed by unique T1 relaxation time. When the contrast of water signals is maximized, regular spin-echo pulse sequence is applied to acquire echoes using delayed echo time of TE+ΔT, where TE is regular echo-time and ΔT is required time-shift of acquisition window to get 90^o phase difference between water and fat. At delayed echo-time, 1. fat spins are orthogonal to both positive and negative-contrast water spins, and 2. positive-contrast water spins have 180^o phase difference from negative-contrast water spins, presenting enhanced-contrast for water signals. In the presence of phase errors (θ) , the acquired image can be expressed as follows [3]:

$$S = (W + jF)e^{j\theta} \quad [1]$$

where F is all positive fat signal, W is positive / negative water signals in the range of $-M_0 < W < M_0$, and M_0 is longitudinal equilibrium magnetization of water spins. Then, using the orthogonality of water and fat signals, $e^{j\theta}$ can be estimated using two independent phase-correction operations using a region-growing algorithm [4] by detecting 180^o phase difference between two positive and negative water signals for the first, and by detecting 90^o phase difference between water and fat signals for the second, sequentially. Once $e^{j\theta}$ is estimated, fat and doubled-contrast water signals can be decomposed such as:

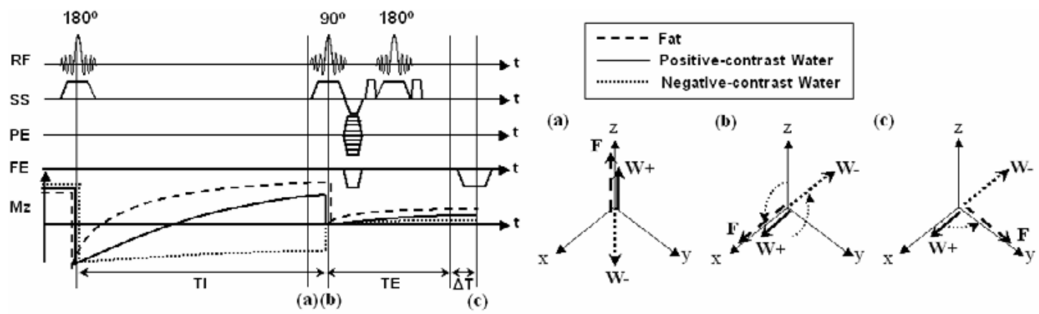

Fig. 1. 'Contrast-enhanced Dixon pulse sequence' and 'Fat' and 'Positive / Negative-contrast Water' spins on the rotating reference frame (a) Before applying 90º RF pulse, (b) After applying 90º RF pulse, and (c) At delayed echo-time, TE+ΔT.

$$S' = Se^{-j\theta} \quad [2] \qquad W = Real\{S'\} \quad [3] \qquad F = Imag\{S'\} \quad [4]$$

Results

Using the 'Contrast-enhanced Dixon pulse sequence,' implemented on 4.7 T Bruker scanner, 'Doubled-contrast Dixon image' was acquired with scan parameters: TE = 30 ms, TR = 500 ms, BW_{RF} = 1 kHz, ST = 3 mm, FOV = 10 cm, ΔT = 186us, and matrix = 256 x 256. A cylindrical phantom having three separate partitions was filled with vegetable oil (T1 = 250 ms, null-time = 173 ms at 4.7 T), distilled water plus 1g/L $CuSO_4$ (T1 = 780 ms, null-time = 540 ms at 4.7 T) and only distilled water (T1 = 4250 ms, null-time = 2946 ms at 4.7 T) to represent fat, positive water and negative water, respectively. To achieve this, inversion time was set to 800 ms, which is intermediate signal-null time of positive / negative water signals. Fig. 2(a) and (d) show phase and magnitude information in the acquired image, for each. There are 180^o phase difference between positive and negative water signals, and 90^o phase difference between fat and positive/negative signals. After two cascaded phase-correction operations (i.e. one is for phase-correction between positive / negative water signals and the other is for phase-correction between water and fat signals), phase-map could be calculated, as we see in Fig. 2(c). After removing background phase-map, fat-only and contrast-enhanced water-only images could be decomposed successfully, as shown in Fig. 2(e) and (f).

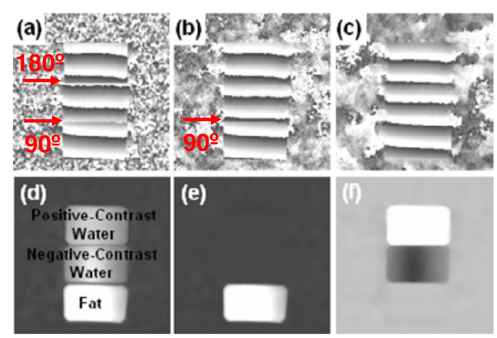

Fig. 2. (a) Phase of acquired image, (b) After 180º phase correction, (c) Final estimated phase-map after 180º phase correction, (d) Magnitude of acquired image, (e) Fat-only image, and (f) Doubled contrast water-only image

Discussion

The proposed pulse sequence produces 90-degree fat phase shift, which allows positive/negative water signals to be recovered without ambiguity. A post-processing phase correction algorithm was used to estimate and correct the background phase variations, which are assumed to be spatially smooth. The phase correction can be normally accomplished without additional scan. Inversion RF pulse increases total scan-time. For scan-time sensitive MR applications, parallel imaging techniques may be combined with the proposed sequence to improve scan-efficiency, while maintaining its benefits.

References [1] Kellman P, et. al., *MRM*, 2002; 47:372-83. [2] Dixon WT, *Radiology,* 153:189 (1984). [3] Ahn, CB et. al., *MRI* 1986; 4:110-111. [4] Akkerman EM, et. Al., *ISMRM,* 3:649 (1995).