A Generalized Dixon Method Incorporating both T1-Contrast and Chemical Shifts

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Introduction

In Dixon techniques, phase changes due to chemical shift are used to separate signals from different species such as water, fat, and SPIO particles [1-3]. The techniques find many clinical MR applications for imaging body parts like shoulder, knee and hips to improve contrast or suppress fat signals [4,5]. However, Dixon techniques assume that tissues to be separated have distinctive chemical shifts. There are potential problems when the chemical shift distributions overlap (e.g., these of the SPIO particles and fat [6]). To address this issue, a novel generalized Dixon technique was developed to include both T1-contrast and chemical shift to extend the Dixon technique's capability to decompose protons that are not separable if only chemical shift was used.

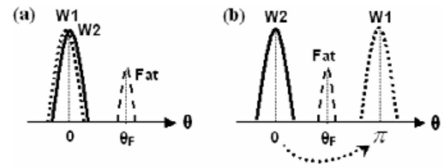

Fig. 1. (a) 'W1' and 'W2' with identical chemical shift but different T1; (b) An inversion pulse will make artificial phase difference between W1 and W2.

Methods

Fig. 1(a) illustrates ambiguity in separating protons using regular Dixon techniques when two different kinds of spins have similar chemical-shift distributions. The main idea of this research is to introduce artificial phase-difference between tissues with different T1 values, so that protons can be differentiated (even they cannot be separated using the conventional Dixon methods. Fig. 2 illustrates a vector model of the evolution of three spin groups (F, W1 and W2) on the rotating frame. At equilibrium, all net-magnetizations are aligned with the main field (Fig. 2(a)). After an inversion RF pulse, inverted longitudinal magnetizations of three protons start to recover at different rates, governed by unique T1 relaxation time of each. When spin directions of two indistinguishable spins become opposite (i.e. at an intermediate signal-null time of two as shown in Fig. 2(b)), regular spin-echo pulse sequence is played 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, fat spins are orthogonal to the other two; and W1 and W2 now have 180^o phase difference (Fig. 2(d)). Conceptually, this 180^o phase shift introduces artificial phase-difference, in addition to those from chemical shift. In the presence of phase errors (θ) , the acquired image can be expressed as follows: $S = (W_2 - W_1 + jF)e^{j\theta}$ [1] where F is fat signal, W_1 is water signal, and W_2 is a proton having similar chemical-shift to water, but with shorter T1 than W_1. Assuming that the image pixels are always dominated by one of the three types of spins, the phase-error θ can be estimated using two independent cascaded phase-correction operations using a region-growing algorithm [7] by detecting 180^o phase difference between W_1 and W_2 for the first, and by detecting 90^o phase difference between F and both W_1 and W_2 for the second. Then, F, W_1 and W_2 can be decomposed by

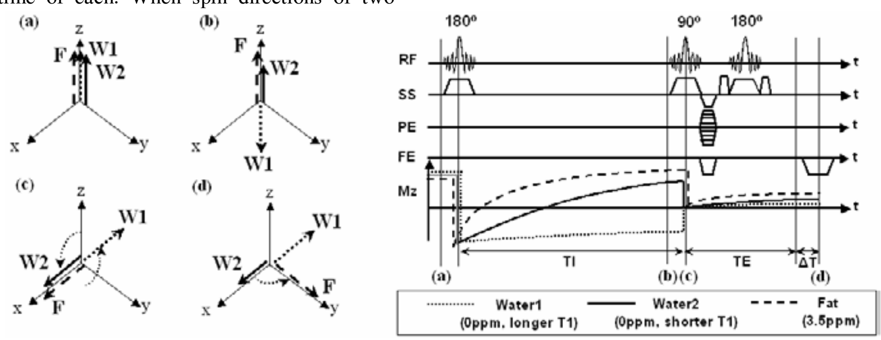

Fig. 2. Pulse sequence of the proposed method (left) and its effect on spin dynamics at different time instance: (a) before the inversion pulse, (b) before 90^o RF pulse, (c) after 90^o RF pulse, and (d) at delayed echo-time, TE+ΔT.

$$S' = Se^{-j\theta} \quad [2] \qquad F = Im\{S'\} \quad [3] \qquad W_1 = (|Re\{S'\}| - Re\{S'\})/2 \quad [4] \qquad W_2 = (|Re\{S'\}| + Re\{S'\})/2 \quad [5]$$

Results

Images were acquired using the pulse sequence shown in Fig. 2 on a 4.7 T Bruker scanner with scan parameters: TE = 30 ms, TR = 500 ms, BW_{RF} = 1 kHz, ST = 3 mm, FOV = 10 cm, ΔT = 186 us, and matrix = 256 x 256. A cylindrical phantom having three separate partitions was filled with vegetable oil (F, T1 = 250 ms at 4.7 T), distilled water (W1, T1 = 4250 ms at 4.7 T), and distilled water doped with 1g/L $CuSO_4$ (W2, T1 = 780 ms at 4.7 T). Inversion time (TI) was set to 800 ms, which is between the signal-null times of W_1 and W_2. Images in Fig. 3(a) and (d) show phase and magnitude of one image. There is 180^o phase difference between W_1 and W_2, and 90^o phase difference between F and W_1/W_2. After two sequential phase-correction operations (i.e. one is for phase-correction between W_1 and W_2, and the other is for phase-correction between F and both W_1 and W_2), phase-map was estimated using a region-growing phase-correction algorithm (shown in Fig. 2(c)). After removing background phase-map, three materials were decomposed into F, W_1 and W_2 successfully, as shown in Fig. 2(e), (f) and (g), respectively.

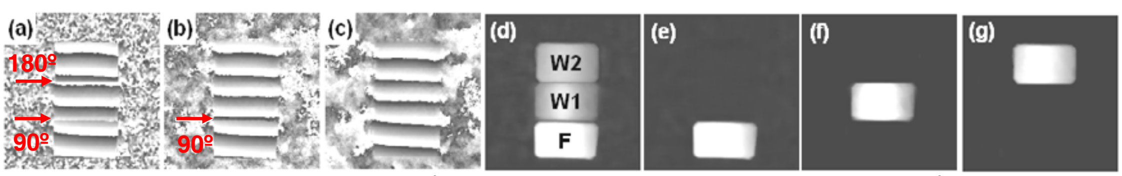

Fig. 3. (a) Phase of acquired image, (b) After 180^o phase correction, (c) Final estimated phase-map after 180^o phase correction, (d) Magnitude of acquired image, (e) Fat-only image, and (f) Water-only image, and (g) Water+$CuSO_4$ only image

Discussion

In addition to the chemical shift-induced phase shift, artificial phase difference could be introduced between two spin groups with different T1s. The generalized Dixon method uses the phase information to separate the otherwise indistinguishable spins with conventional Dixon methods. The method was verified for separating three tissues types using phantom studies. The method can be extended and further tested for in-vivo imaging the SPIO particles where separation of water, fat and SPIO particles is desirable.

References [1] Ahn, CB et. al., *MRI* 1986; 4:110-111. [2] Reeder SB, et. al., *ISMRMI,* 14:430 (2006). [3] Koktzoglou I, et. al., *ISMRM,*14:431 (2006). [4] Haacke EM, et. al., *MRM,*1:123 (1986). [5] Dixon WT, *Radiology,* 153:189 (1984). [6] Shah SS, et. al., *ISMRMI,* 14:3499 (2006). [7] Akkerman EM, et. Al., *ISMRM,* 3:649 (1995).