Fat Water Separation using a Prepulse for Short Echo Space FSE

Andrew J Wheaton[1]
[1]Toshiba Medical Research Institute USA, Mayfield Village, OH, United States

INTRODUCTION

In spin-echo (SE) or fast spin-echo (FSE) sequences, the Dixon effect (1) can be achieved by time shifting either the position of the first RF refocus pulse (2) or the position of the read echo (k_x=0) within the inter-echo spacing (3,4). The approach of shifting the position of the read echo either extends inter-echo spacing by a full cycle time (4.6 ms at 1.5T and 2.3 ms at 3T) (3) or forces asymmetric echo acquisition (4). This constraint places restrictions on the application of Dixon-based techniques for FSE, especially for short inter-echo space 3D FSE (i.e. SPACE, CUBE).

WFOP-PREPARATION PULSE SEQUENCE

The Water-Fat Opposed-Phase preparation (WFOP-prep) sequence enables Dixon SE / FSE image acquisition without imposing restrictions on inter-echo spacing or readout. The WFOP-prep sequence consists of two 90° flip pulses (Figure 1). The 90° RF pulses of the WFOP-prep sequence can be made slice- or slab-selective. For this simple proof-of-concept study, we used non-selective pulses. The RF pulses are separated by an interpulse period τ (=1.15 ms at 3T). The relative transmit phase of the RF pulses is a design parameter which affects the water-fat evolution as will be further discussed. In the simplest scheme the transmit phase is opposite (+x:-x).

The first RF pulse nutates longitudinal magnetization into the transverse plane. The relative phase angle between fat and water evolves during τ. After τ, the transverse magnetization is nutated into the longitudinal axis, thereby storing the phase angle between fat and water. The opposed-phase longitudinal magnetization is then read using <u>any</u> conventional SE or FSE readout, without the need for pulse / echo shifting or readout adjustment. The refocus pulse(s) of the echo train realign the transverse magnetization with its original relative phase (fat-water opposed) at each echo.

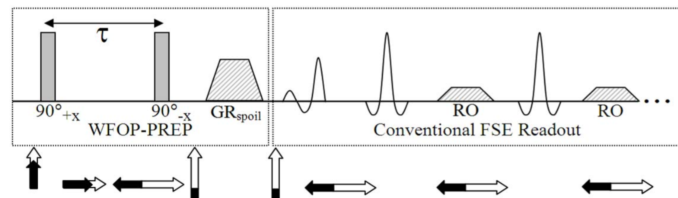

Fig 1. Sequence diagram of WFOP-prep sequence attached to conventional FSE readout. The evolution of fat (solid arrow) and water (open arrow) isochromats is displayed.

WFOP-PREP for FAT-WATER SEPARATION

Since τ is a free parameter, WFOP-prep can be used for multi-point Dixon fat-water separation. Multiple WFOP-prep image sets can be acquired with different τ. Background off-resonance phase accrual during the τ period causes sinusoidal signal modulation resulting in signal loss at the zero-crossings. To compensate for this signal loss, the relative transmit phase of the RF pulses can be adjusted. For example, a transmit phase scheme of 90_{+x}:90_{+y} (Figure 2B) produces peaks where the 90_{+x}:90_{-x} scheme (Figure 2A) produces troughs. Thus, a shift of π/2 in RF transmit phase is equivalent to a π/2 shift in the sinusoid response.

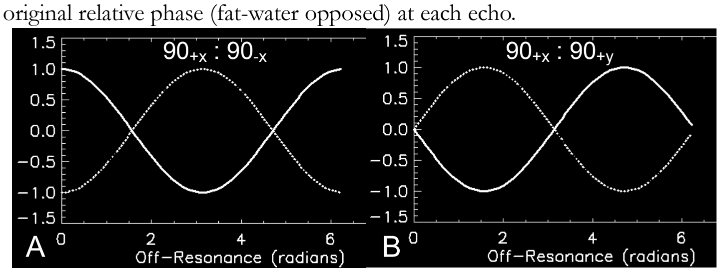

Fig 2. Magnitude signal of water (solid) and fat (dashed) relative to off-resonance for WFOP-prep (τ=π) using RF transmit phase: A) 90+x : 90-x and B) 90+x : 90+y.

Due to the off-resonance related signal loss, a minimum of three images are required for practical application. For simplicity, we label these images A:(τ=π,+x:-x), B:(τ=π,+x:+y), and C:(τ=2π,+x:-x). Additional images can be included using different τ and RF phase schemes. In our example, we include D: (τ=2π,+x:+y). We can describe the linear system (Equation 1) for water spin density (ρ_w), fat spin density (ρ_f), and background phase (φ). The system of equations can be written in matrix format and solved using standard matrix inversion methods. For our work, we employed SVD.

A key aspect of this method is that the input pixel data [A,B,C,D] is signed magnitude data, not complex data. A simple phase map for φ can be derived from the A and B data sets using $\varphi=\tan^{-1}(B/A)$. Alternatively, φ data can come from an external source (i.e. shim field map) or be iteratively solved as part of the solution to Equation 2. There is no need for phase unwrapping because the signed magnitude data only cares about relative phase, not absolute phase

$$\begin{aligned} A &= (\rho_w - \rho_f)\cdot\cos\phi \\ B &= (\rho_w - \rho_f)\cdot\sin\phi \\ C &= (\rho_w + \rho_f)\cdot\cos 2\phi \\ D &= (\rho_w + \rho_f)\cdot\sin 2\phi \end{aligned}$$

Equation 1

$$\begin{bmatrix}\rho_w \\ \rho_f\end{bmatrix} = \begin{bmatrix} \cos\phi & -\cos\phi \\ \cos 2\phi & \cos 2\phi \\ \sin\phi & -\sin\phi \\ \sin 2\phi & \sin 2\phi \end{bmatrix}^{-1} \begin{bmatrix} A \\ C \\ B \\ D \end{bmatrix}$$

Equation 2

METHODS

The brain of a male volunteer was scanned on a 3T whole-body research system under IRB approval. Axial partial-Fourier 3D FSE with WFOP-prep was acquired with the following parameters: TE/TR = 80/3000 ms, echo space = 5.0 ms, 2 shots, ETL = 80, matrix = 256 x 256, partial Fourier factor = 5/8, FOV = 25 x 25 cm, sixteen 3 mm partitions, and readout BW = 651 Hz/pixel. Four image sets were acquired corresponding to the A, B, C, and D descriptions above. Fat and water images were reconstructed using the method described.

RESULTS & DISCUSSION

Representative water and fat separations images are displayed in Figure 3. The WFOP-prep sequence enabled Dixon image acquisition with a conventional short echo space FSE readout. The choice of echo-spacing, readout bandwidth, and other sequence parameters can be made without regard to the τ time. This freedom allows FSE-based Dixon methods to be used in conjunction with applications with short echo-spacing, such as single-shot FSE or 3D FSE (i.e. SPACE, CUBE).

Since the relative phase angle is developed as part of the prepulse, and not the readout, the data at each τ time is acquired with identical contributions from other sequence-dependent sources of phase (i.e. eddy currents) and stimulated echo signal. This uniformity in all data sets can help simplify analysis of the multi-point Dixon data.

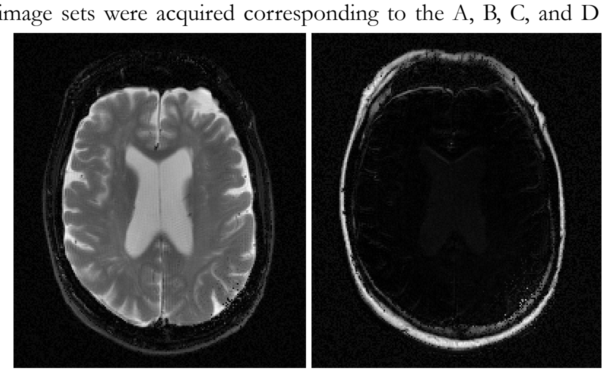

Fig 3. Representative water and fat images using WFOP-prep.

Since the WFOP-prep requires multiple acquisitions, it is not a suitable replacement for existing fast water/fat separation techniques (i.e. VIBE, LAVA, IDEAL) which can be applied in a single breathhold. We plan to study the application of this technique in other stationary anatomy where the combination of water/fat separation with high resolution of 3D FSE is beneficial (i.e. ortho).

REFERENCES: 1. Dixon WT. Radiology 1984;153:189-194. **2.** Higuchi N, Hiramatsu K, Mulkern RV. Magn Reson Med 1992;27:107-117. **3.** Hardy PA, Hinks RS, Tkach JA. J Magn Reson Imag 1995;5:181-185. **4.** Ma J, Singh SK, Kumar AJ, Leeds NE, Broemeling LD. Mag Reson Med 2002;48:1021-1027.