Improving image contrast and water/fat quantitation in Dixon methods using a multi-spectral fat model

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INTRODUCTION:

The multiple spectral nature of fat is well-known (*1*). Yet, a fundamental assumption in Dixon water/fat imaging is that the spectrum of water and fat each consists of a single peak that is separated by ca. 3.35 ppm. As a consequence, spectral leakage in water and fat separation and incorrect water and fat quantitation can occur (*2*). In this paper, we demonstrate that improved image contrast and more accurate water/fat quantitation can be achieved by considering fat as a system with two spectral components.

METHODS:

When fat is modeled as a single peak, the phase of its MR signal relative to water is proportional to the echo shift τ. The amplitudes of the water and fat signals are generally assumed constant when the relaxation effects are ignored. In conventional two-point Dixon technique, two images, S_{in} and S_{out}, are collected with echo shifts corresponding to 0 and 180° phase shifts, respectively. Under the single peak model, the water and fat signals can be obtained as $W=(S_{in}+S_{out})/2$, $F=(S_{in}-S_{out})/2$ after phase correction. As a refinement to the single peak model, we assume that the multiple fat peaks are approximated with two spectral components, with each representing a group of peaks with resonance frequencies that are close to each other. The first peak has the dominant contribution from methylene and an average resonance frequency ω_1 (which is approximately 3.35ppm from the water resonance). The second peak has the dominant contribution from olefinic protons and an average resonance frequency ω_2 (which is close to the water peak). When the amplitudes of these two spectral components are represented as $\rho_1 F$, and $\rho_2 F$, respectively, the complex signal when the echo shift is set to τ can be expressed as in Eq. [1]:

$$S = C \cdot (W + \rho_1 \cdot F \cdot e^{-i\omega_1 \tau} + \rho_2 \cdot F \cdot e^{-i\omega_2 \tau}) \qquad [1] \qquad W = ((\rho_1 - \rho_2) \cdot S_{in} + S_{out})/2\rho_1 \qquad [2] \qquad F = (S_{in} - S_{out})/2\rho_1 \qquad [3]$$

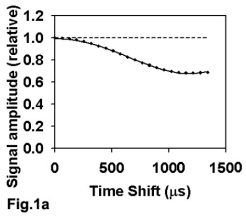
Where C is a τ-independent scaling factor. Under the assumption that $\omega_2 \approx 0$, the water and fat signals can be determined from the in-phase and out-of-phase signals as in Eqs.[2-3].

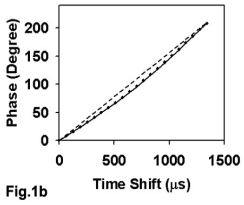
For the experiment, we used a cylindrical water/fat phantom filled with equal amounts of copper sulfate solution (10mM/L in concentration) and pure vegetable oil. A standard spin echo pulse sequence was modified by time-shifting the 180° RF refocusing pulse towards the 90° excitation pulse. We studied the signal behavior by systematically acquiring images with different time shifts for the refocusing pulse and by acquiring images at different TR and TE times. In-phase and out-of-phase data were also acquired of a healthy volunteer and separate fat and water images were generated using both single peak and bi-peak models. All experiments were performed on a GE Signa 1.5T system using the following imaging parameters: TR/TE=100-600/14~100ms for phantom and TR/TE=650/14ms for in vivo, RBW=16 kHz, acquisition matrix=256x160, FOV=20x20cm.

RESULTS:

Fig.1a) and 1b) show the fat signal amplitude and phase respectively as a function of the time shift of the refocusing RF pulse (dots = experimental data, solid line = simulation using bi-peak model, dashed line = simulation using a single peak model). Clearly, the bi-peak model fits the experimental data better than the single peak model, particularly at large time shifts. Using a least square fit to the signal according to Eq. [1], we obtained ω_1= 210.0Hz, ω_2= –2.0Hz, ρ_1= 0.84, ρ_2= 0.16. These results and the quality of the fit provide support to the approximation used to derive Eqs. [2-3]. From the experiment where TR and TE were varied, we found that TR has a negligible effect on the signal phase. In contrast, increasing TE reduces the phase errors by the single peak model. We attribute such effect to the different T2-relaxation for different fat spectral components (*1*).

Fig. 2 shows respectively the combined (a), fat-only (b), water-only images according to the single peak model (2c) and the water-only image according to the bi-peak model (2d). As indicated, the water-only image according to the single peak model shows considerable signal intensity in the fat-only region. By comparison, this erroneous signal intensity is largely removed by the two-peak model. The improvement in the fat quantitation can also be appreciated in the leg images of a healthy volunteer (Fig. 3a-d), where the image by the two-peak model (Fig. 3d) demonstrates increased water/fat contrast over the image by the single peak model (Fig. 3c).





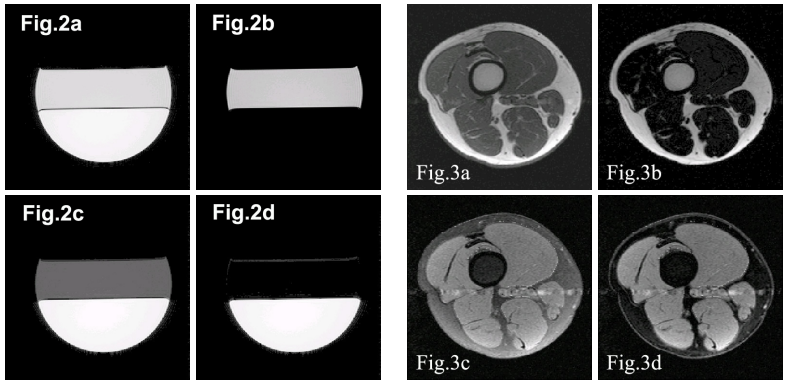


Fig 1. Fat signal amplitude (1a) and phase (1b) as function of time shift of refocusing RF pulse.

Fig 2. (a) in-phase image. (b) fat-only image. (c) water-only image by the single peak model. (d) water-only image by the bi-peak model.

Fig 3. (a) in-phase image. (b) fat-only image. (c) water-only image by the single peak model. (d) water-only image by the bi-peak model.

CONCLUSIONS:

We demonstrated in this research that the amplitude and phase of the signals acquired in a two-point Dixon technique were better described by assuming fat as consisting of two instead of a single spectral peaks. We conclude based on our phantom and in vivo experiments that for improved image contrast and more accurate water and fat quantitation, the multiple spectral nature of fat should be taken into account.

REFERENCES:

(1) K. Kuroda et al, MRM, 40, 505-510 (1998) (2) J. Ma et al, MRM, 48,1021-1027 (2002)