Influence and Compensation of Fat Signal Dephasing and Decay in Two-Point Dixon Imaging

H. Eggers[1]
[1]Philips Research, Hamburg, Germany

Introduction

Dixon methods do not only provide a more robust fat suppression in the presence of field inhomogeneity than selective saturation and excitation methods, but also promise a more complete fat suppression, when multi-peak spectral models of fat are employed in the separation. The latter has convincingly been demonstrated for a three-point method lately [1]. In this work, such models are incorporated into a novel two-point method with unrestricted choice of echo times [2], and the influence of fat signal dephasing and decay, both without and with consideration in the separation, on the extent of fat suppression in two-point Dixon imaging is studied.

Methods

The composite signal S in image space at echo time TE is modeled by

$$S_n = (W + c_n F)e^{i\varphi_n}, \text{ with } c_n = \sum_m w_m e^{i\theta_{n,m}}, \sum_m w_m = 1,$$

where W and F are the water and fat signal in image space, φ is a common phase, w is a weight, and Θ is the dephasing angle between a peak of the spectral model of fat and water at TE. Optionally, relaxation may be included by an additional factor describing the exponential decay with TE. The weights, resonance frequency offsets, and relaxation rates are assumed to be known a priori, either from literature or measurements [1,3].

For the separation, first potential solutions for W and F are calculated, similar to Ref. [4]. From the two equations:

$$|S_{1/2}|^2 = W^2 + 2c_{1/2R}WF + |c_{1/2}|^2F^2, \text{ with } c_{nR/I} = \Re/\Im\{c_n\},$$

a biquadratic equation is obtained. Solving for F, for example, yields

$$a_1F^4 + a_2F^2 + a_3 = 0, \text{ and thus } F_{1/2}^2 = \frac{-a_2 \pm \sqrt{a_2^2 - 4a_1a_3}}{2a_1}, \text{ with}$$

$$a_0 = c_{1R}^2 - c_{1I}^2 - 2c_{1R}c_{2R} + |c_2|^2, \; a_1 = a_0^2 + 4(c_{1R} - c_{2R})^2 c_{1I}^2,$$

$$a_2 = 2a_0(|S_1|^2 - |S_2|^2) - 4(c_{1R} - c_{2R})^2|S_1|^2, \; a_3 = (|S_1|^2 - |S_2|^2)^2.$$

For a single-peak spectral model without relaxation, radical denesting leads to the simpler expression given in Ref. [4]. Potential solutions for the phasor $\Delta P = e^{i(\varphi_2 - \varphi_1)}$ are then obtained by evaluating

$$\Delta P = \frac{S_1^* S_2}{(W + c_1^* F)(W + c_2 F)}$$

for all pairs of corresponding values of W and F. Finally, the selection of one of the solutions and the subsequent recalculation of W and F is performed as in the case of a single-peak spectral model without relaxation, just with the modified signal equation.

Simulations were performed with a seven-peak spectral model derived from Ref. [3], which also served as a priori knowledge in the subsequent experiments on volunteers, conducted on 1.5 T scanners (Philips Healthcare, Best, Netherlands) with 16 or 32 element receive coils and a 3D spoiled multi-gradient-echo sequence.

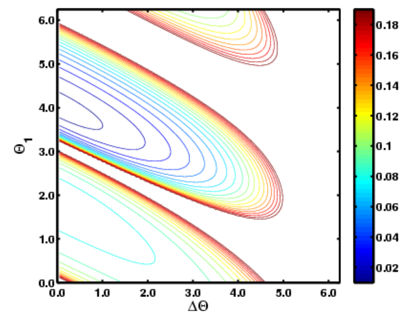

Fig. 1. Leakage of fat signal into water signal. Plotted is the fraction of a pure fat signal that the separation outputs as water signal, as function of the dephasing angle Θ_1 at the first echo time and the increment in the dephasing angle $\Delta\Theta$ between the two echo times.

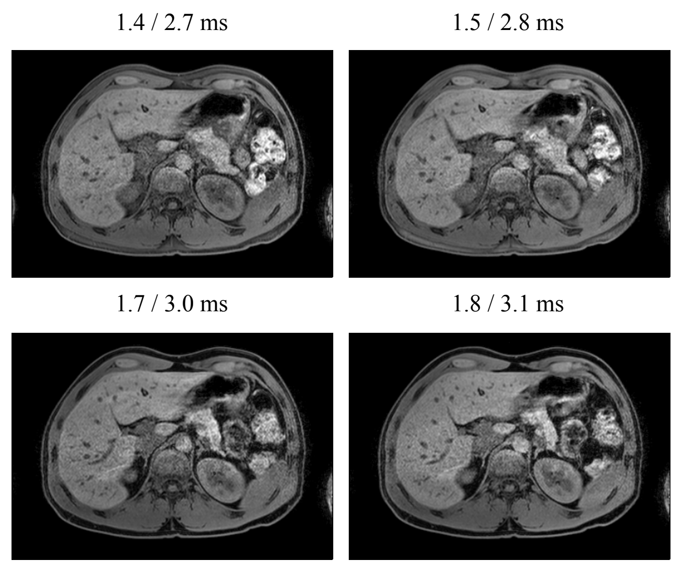

Fig. 2. Comparison of fat suppression at different echo times. Shown are selected water images produced with a single-peak spectral model from, except for the two stated echo times, identical acquisitions.

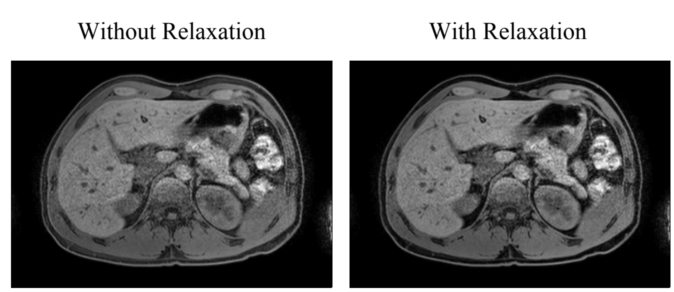

Fig. 3. Water images corresponding to the upper right example in Fig. 2, produced with a multi-peak spectral model without and with consideration of relaxation.

Results

In Fig. 1, the extent of fat leakage is quantified for a range of echo times. A single-peak spectral model without relaxation was employed in the separation. While the fat leakage generally increases with longer echo times, it is apparently advantageous to choose the first echo time rather more out than more in phase. This is confirmed by the image series in Fig. 2, in which this condition is met in the lower two examples. Θ_1 of the dominant peak was successively incremented from 1.9 to 2.5, while $\Delta\Theta = \Theta_2 - \Theta_1$ was kept fixed at 1.8. The inferior fat suppression in the upper two examples is improved using a multi-peak spectral model and is further enhanced considering relaxation, as demonstrated in Fig. 3 for the worse of the two cases.

Conclusions

Using a simple single-peak spectral model of fat without relaxation in the separation, the extent of fat suppression in two-point Dixon imaging strongly depends on the choice of echo times. Only if the fat signal dephasing and decay is stronger at the more in phase echo time, the separation favors the dominant signal component and thus achieves a more complete fat suppression. Incorporating a more complex spectral model of fat into the separation is possible and is key to achieving a more uniform degree of fat suppression across a range of relevant echo times.

References

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