Fat-Fat Interations in Dixon-Variant Imaging

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As reported in (1,2), the dependence of the signal S on echo time t from a sample containing n components is a summation of the individual signals given by Eq 1, where ω is the chemical shift, υ is the T2* relaxation rate and ψ is the field map.

$$S(t) = \sum_{j=1}^{n} S_j \exp(i\omega_j t)\exp(\nu_j t)\exp(i\psi t) \qquad [1]$$

Modeling the signal variation with echo time provides a way to account for the T2* and chemical shift effects in order to estimate the S_j accurately. This is used for fat suppression or quantification purposes. Various ways of doing this have been proposed although usually by making simplifications to reduce the complexity of the model: (I) n = 2; (II) ω_j are known; (III) υ_j are equal or zero; (IV) ψ is spatially smooth. The purpose of this study is to investigate the minimal set of simplifications that can provide a practical, accurate method for fat quantification.

A way to reduce the complexity without making any approximations is to take the amplitude (3), which eliminates assumption (IV). With this approach the number of data points is reduced by half, since the real and imaginary data points are replaced by a single magnitude data point. However, the real and imaginary data points constitute repeat measurements at the same echo time and taking the magnitude effectively averages these data points, which increases their SNR.

$$|S(t)| = \mathrm{sqrt}\left[\sum_{j=1}^{n}\sum_{k=1}^{n} S_j S_k \exp(\nu_j t + \nu_k t)\cos(\omega_j t - \omega_k t)\right] \qquad [2]$$

A way to further reduce complexity is to invoke assumption (II) using ω_j determined from spectroscopy. Fat has a complex chemical spectrum (Fig 1). Principally there are five peaks corresponding to C**H**=C**H**, CH=CHC**H**$_2$CH=CH, C**H**$_2$COOR, -(C**H**$_2$)- and C**H**$_3$ at 5.3, 2.8, 2.2, 1.3 and 0.9 ppm. The area under each peak gives the relative proportions, which are 0.2, 0.1, 0.2, 1.0 and 0.2 for this spectrum. The broadness is a measure of the T2: a narrow peak indicates a long T2.

While in principle it is possible to model every peak, even with assumption (II) the number of unknowns in Eq 2 is $2n$–1 so many more than $2n$–1 data points must be acquired to perform curve-fitting, which is not practical for n>2 in a time-constrained clinical examination. Thus it is necessary to invoke assumption (I), i.e. n = 2. Two models are proposed that use this approach yet account for some of the complexities of the full spectrum of fat.

<u>n = 2 broad peak (BP) model</u> [4 unknowns: S_1 S_2 υ_1 υ_2]
In this model peaks 1 & 2 are neglected and the remaining peaks 3, 4 & 5 are considered to behave like a single broad peak. As noted above, the broadness represents (at least in part) the T2 decay so a broad fat peak should manifest as a decreased apparent T2* decay of fat. Thus the BP model cannot make assumption (III) because the components are expected to have different T2*. The short apparent T2* effect has been observed in data from fatty liver patients (4).

<u>n = 2 composite peak (CP) model</u> [3 unknowns: S_1 S_2 υ]
In this model a composite fat component, based on spectroscopy, is assumed with the constraint that all the fat components are correlated. That is, there are a fixed number of peaks at specific chemical shifts and in specified relative proportions, see above. Thus in the CP model the different fat peaks exist as a single entity. This approach properly accounts for fat-fat interference so there is no short apparent T2* effect; therefore it is valid to invoke assumption (III) in this model.

Results

Fig 2 & 3 shows the signal in vegetable oil, water and a 50:50 oil-water mixture measured with a gradient echo sequence (Siemens 1.5T, TE 2–15 ms, TR 200, α = 45°). Note that the oil exhibits interference phenomena as a consequence of the interactions between the different peaks. The lines show best-fit curves to the BP and CP models, respectively.

Fig 1 *Spectrum of vegetable oil*

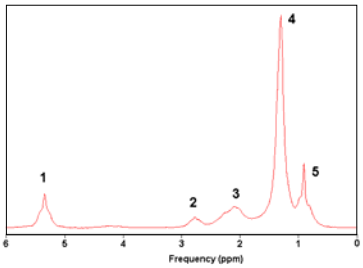


Fig 2 *Signal vs TE (BP model)*

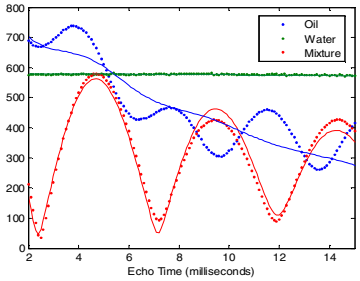
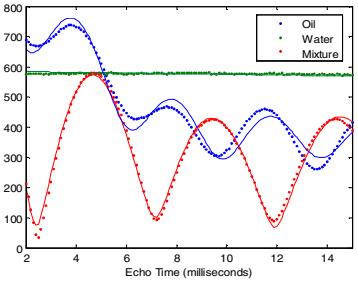


Fig 3 *Signal vs TE (CP model)*



Conclusion

The proposed models capture many of the subtle interactions between fat and water, such as the apparent short T2* and fat interference effects. In particular, the CP model very closely follows the signal in fat, water and fat-water mixtures.

References (1) Dixon. *Radiology* 1984;153:189 **(2)** Reeder et al. *MRM* 2004;51:35 **(3)** Ford et al. *MRM* 1991;17:543 **(4)** Bydder et al. *ISMRM* 2006:2298