Effects of T1 and T2* Relaxation on Fat Quantification by Gradient Echo Imaging

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Introduction

One of the most commonly used magnetic resonance methods for fat detection and quantification is gradient recalled echo (GRE) imaging (1). Images are acquired at two echo times (TEs) at which the signals from fat protons (F) and water protons (W) are presumed to be exactly in-phase (IP) and out-of-phase (OP). Since these images are acquired with a ΔTE that is short relative to the T2*, it is normally assumed that T2* decay is negligible and all signal variation between the two TEs is due to the phase interference of the fat and water protons. Under these conditions, the IP, OP and fat fraction (FF) can be estimated as

$$IP = W + F \qquad [1]$$

$$OP = W - F \qquad [2]$$

$$FF = (IP - OP) / 2IP \qquad [3]$$

This simple technique is clinically used as an indicator for the presence of fat although it is known empirically to be inadequate when T2* decay is significant (2). It is also known that differences in T1 relaxation between water and fat introduce a dependence on imaging parameters such as repetition time and flip-angle (3). The present study aims to characterize the effects of relaxation on the measured fat fraction.

Methods

The consequences of T1 and T2* relaxation can be investigated theoretically by substituting the MR signal equations for W and F in the above expressions and seeing how the FF estimated by Eq 3 is affected.

$$W = W_0 \ \exp(-TE/T2_w^*) \ . \ (1 - \exp(-TR/T1_w))\sin(\alpha) / (1 - \exp(-TR/T1_w)\cos(\alpha)) \qquad [4]$$

$$F = F_0 \ \exp(-TE/T2_f^*) \ . \ (1 - \exp(-TR/T1_f))\sin(\alpha) / (1 - \exp(-TR/T1_f)\cos(\alpha)) \qquad [5]$$

By making certain approximations, a greatly simplified analytical expression for FF can be obtained: $\alpha = 90°$, $T2_w^* = T2_f^*$, $\Delta TE << T2_{w,f}^*$ and $TR << T1_{w,f}$. While these are only partly justified, numerical simulations indicate that similar results are obtained when the approximations are used compared to the full equations.

$$FF \approx A_1 A_2 FF_{true} \qquad [6]$$

$$A_1 = R / (1 + (R-1) FF_{true}) \qquad [7]$$

$$A_2 = 1 - (\Delta TE/T2^*)(1/(2FF_{true} - 1) \qquad [8]$$

In these equations $FF_{true} = F_0 / (W_0 + F_0)$ is the true fat fraction, R is the ratio $T1_w / T1_f$, A_1 is a T1 amplification factor and A_2 is a T2* amplification factor. A notable observation in these expressions is that the amplification factors depend on FF_{true} and therefore the effects of relaxation on the measured FF are nonlinear.

Results

A plot of FF *vs* FF_{true} is shown in Figure 1 for a typical set of imaging parameters applicable to liver imaging: TR=100 ms, α=90°, ΔTE=2.2 ms, $T1_w$=490 ms, $T1_f$=260 ms, $T2_w^*$=20 ms and $T2_f^*$=10 ms (4). The solid line shows the results from the full expression while the dotted line shows results of the analytical expression (Eq 6). Figure 2 shows the amplification factors A_1 (solid line) and A_2 (dotted line) given by Eq 7 and 8.

Figure 1: Measured *vs* true fat fraction

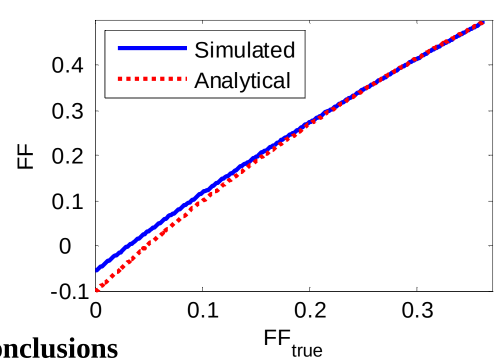
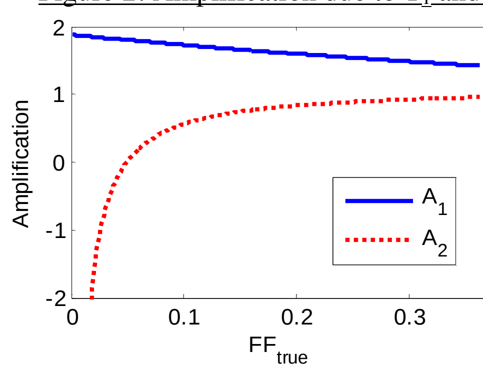


Figure 2: Amplification due to T_1 and T_2



Conclusions

Without any correction for T1 and T2* relaxation, a plot of the fat fraction measured by GRE versus the true fat fraction should be nonlinear with a negative intercept. This is important for validating MRI methods of quantification against a gold standard (e.g. spectroscopy, histology), where a linear correlation is often assumed.

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