**R2* estimation in the presence of fat and macroscopic B0 field variations**

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**Introduction:** Quantitative, non-invasive estimation of \( R^*_2 \) is an important biomarker of hepatic iron overload. Unfortunately, estimates of \( R^*_2 \) may be confounded by the presence of fat, as well as the signal dephasing that occurs from macroscopic magnetic field gradients caused by external susceptibility. This can lead to systematic error in the \( R^*_2 \) maps [1-3], potentially complicating the detection and quantification of iron overload. In this work, we extend complex chemical shift based fat-water imaging methods that provide simultaneous, unconfounded estimates of water, fat, \( R^*_2 \) and Bo field maps. Using the Bo field maps, estimates of \( R^*_2 \) that are corrected for macroscopic susceptibility can be achieved.

**Theory:** The complex-valued signal in a multi-echo SPGR acquisition can be modeled as follows, including \( R^*_2 \) decay [4,5], multi-peak fat signal [4], and macroscopic field effects [1-3]:

\[
s_{\text{model}}(TE;W,F,R_2^*,f_\text{B}) = (W + F \, c_\text{f}(TE) \exp[-R^*_2 \, TE] \, \exp[2\pi f_\text{B} \, TE]) \, h(TE),
\]

where \( W \) and \( F \) are the water and fat signal amplitudes, respectively, \( c_f(TE) \) is the multi-peak fat signal model (fat peaks with frequencies \( f_\text{B} \) and relative amplitudes \( a_\text{B} \), respectively) [4], \( R^*_2 = 1/ T^*_2 \), \( f_\text{B} \) is the local frequency offset due to Bo field inhomogeneity, and \( h(TE) \) accounts for the additional signal decay caused by macroscopic Bo variation within each voxel. The additional decay \( h(TE) \) is generally non-exponential, and is a confounding factor for \( R^*_2 \) estimation (typically leading to overestimation of \( R^*_2 \) if not accounted for). Assuming constant signal amplitude and linear Bo variation \( (\text{gradient } g_\text{B}) \) over the voxel (with spatial response function \( SRF(\vec{r}) \)), \( h(TE) \) can be expressed as:

\[
h(TE) = \int SRF(\vec{r}) \exp[2\pi f_\text{B} \, \vec{r}] \, d\vec{r}
\]

where \( SRF(\vec{r}) \) can be approximated as a rect function in the slice direction for 2D experiments (in which case the typically dominant through-slice decay is a sinc function), and a sinc-like function in 3D experiments (in which case the decay can be approximated numerically by integrating over the main lobe of the sinc). An initial Bo map estimate obtained (from the same data) using the standard fat-water signal model (without \( h(TE) \)) is used to calculate the gradient \( g_\text{B} \) needed for the Bo-corrected model.

**Experiments:** An oil-water-iron phantom was built as in Ref. [6], with fat-fractions (FFs) of 0, 5, 10, 20 and 30%, and SPIO (Ferridex, Bayer Inc., Wayne, NJ) concentrations of 0, 25, 50, 75 and 100 mg/l. Phantom data were acquired at 1.5T using an investigational version of a 3D multi-echo SPGR ‘IDEAL’ sequence, with FA=10°, slice thickness 4mm and 15 echoes (TE=1.3ms and ΔTE=0.7ms, obtained in three interleaved ‘shots’). The phantom vials were positioned parallel to the Bo field, and 11 axial datasets were obtained by intentionally varying the shim gradient along the “z” direction over a range of 0-10 Hz/mm, in order to generate controlled macroscopic magnetic field gradients. Additionally, liver data were acquired in patients with fatty liver disease, in accordance with our Institutional Review Board, using a 3D SPGR IDEAL sequence with FA=5°, slice thickness 10mm and 6 echoes (TE=1.20ms, ΔTE=2.00ms).

**Results and Discussion:** Figures 1 and 2 show \( R^*_2 \) estimation results from a water-oil-iron phantom and liver acquisition, respectively. As the Bo gradient increases, the standard fat-water model (including multi-peak fat and \( R^*_2 \), but no background Bo variation) results in severe overestimation of \( R^*_2 \) (up to ~20 s⁻¹ in the phantom and 20 s⁻¹ in the liver). The Bo-corrected method is able to largely remove this overestimation.

A limitation of the proposed method is that it uses a locally linear model for Bo variations. In regions of very severe susceptibility-induced field variation (with significant higher order terms in the Bo field variation), it is still advantageous to acquire thinner slices, which result in reduced susceptibility effects and allow better approximation by a locally linear Bo.

**Conclusion:** Improved mapping of \( R^*_2 \) in the liver can be achieved by correcting for confounding factors, including macroscopic Bo variations and the presence of fat. The proposed method uses the complex signals to estimate and correct for macroscopic Bo variations.


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