Free-Breathing Liver Fat and R_2^* Mapping: Multi-Echo Radial FLASH & Model-based Reconstruction

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INTRODUCTION

Fat is a metabolically active component of the human body. Excessive fat in the liver can progress into fibrisis and liver cancer. Chemical-shift encoded magnetic resonance imaging (MRI) [1, 2, 3] has been proven capable of non-invasively quantifying fat fraction in the liver. To work well, these methods require lengthy breath holding and high signal-to-noise (SNR) images. This study aims to develop a free-breathing liver fat and R_2^* quantification technique using multi-echo radial FLASH and model-based reconstruction (MERLOT).

METHODS

Multi-Echo Radial FLASH Sampling

Figure 1 illustrates the implemented multi-echo radial FLASH MRI sequence [4]. After a radio frequency (RF) excitation with the slice-selection gradient (G_z), seven echoes with different k-space spokes are acquired. The acquired echoes are color coded, while the black solid lines indicate either the ramp or the blip gradients.

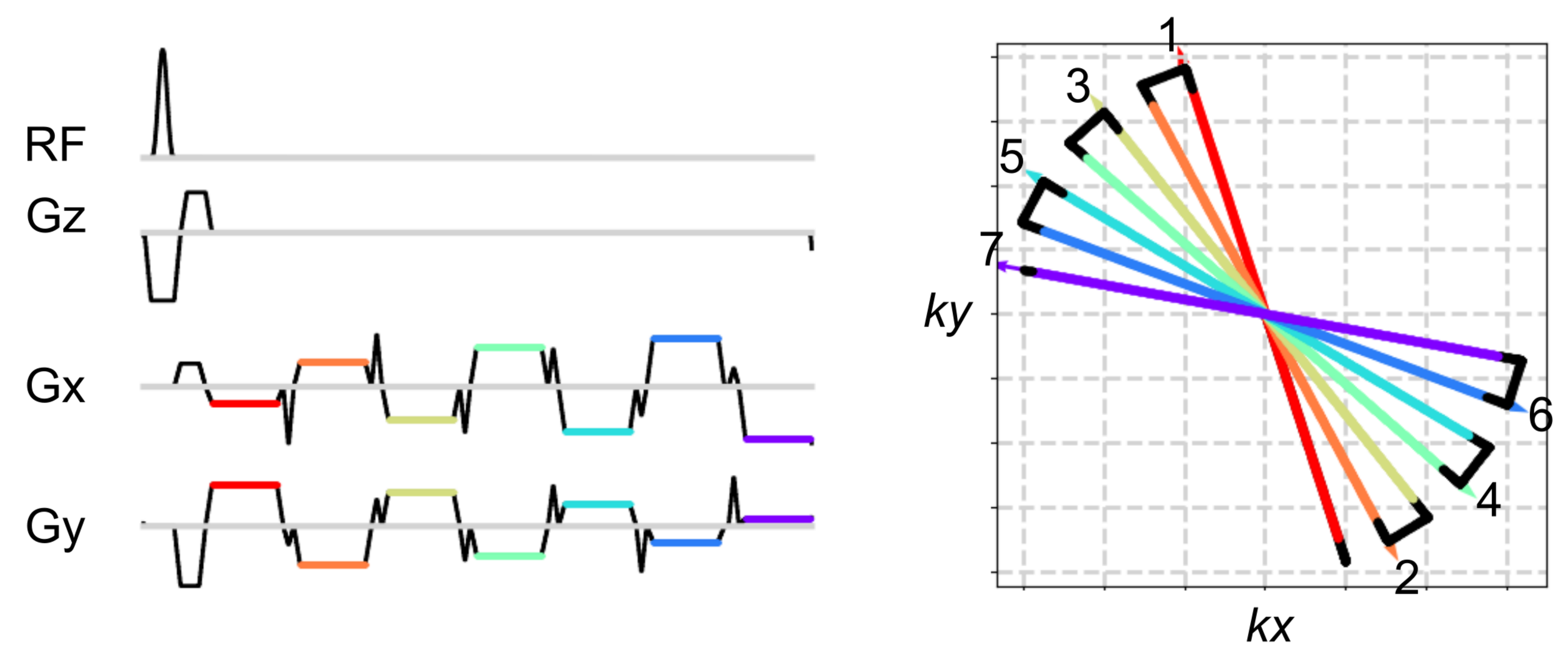

Figure 1: (Left) A repetition block of the multi-echo radial FLASH sequence. (Right) The corresponding k-space trajectory.

Model-based Reconstruction

The acquired MR signal, $y_{j,m}(t)$, is based on the Fourier transformation:

$$y_{j,m}(t) = \int \mathrm{d}\vec{r}\, e^{-i2\pi\vec{k}(t)\cdot\vec{r}} c_j(\vec{r})\rho_m(\vec{r}) \,. \quad (1)$$

The sampling trajectory $\vec{k}(t)$ is from the time integral of readout gradients G_x and G_y (see **Figure 1**). When one image voxel contains both water (W) and fat (F) species, the echo image ρ_m is modeled as:

$$\mathcal{B} : (\mathrm{W}, \mathrm{F}, R_2^*, f_{B_0})^T \mapsto \rho_m : \left(\mathrm{W} + \mathrm{F} \cdot z_m\right) \cdot e^{-R_2^* \mathrm{TE}_m} \cdot e^{i2\pi f_{B_0} \mathrm{TE}_m} \,. \quad (2)$$

Here, $z_m = \sum_{p=1}^{6} \alpha_p \cdot e^{i2\pi f_p \mathrm{TE}_m}$ denotes the six-peak fat spectrum. R_2^* and f_{B_0} is the transversal relaxation rate and magnetic field inhomogeneity, respectively. Equations (1) and (2) can be chained together and written in the operator form,

$$y_{j,m} = F_{j,m}(x) := P_m \mathcal{F} M \mathcal{S} \mathcal{B} \,, \quad (3)$$

with $x = (\mathrm{W}, \mathrm{F}, R_2^*, f_{B_0}, c_1, \cdots, c_N)^T$. $F_{j,m}(x)$ denotes the forward operator. j is the the coil index ($j \in [1, N]$), and m the echo index ($m \in [1, E]$). The nonlinear operator ($\mathcal{B}$) calculates echo images. Every echo image is then point-wise multiplied by a set of coil sensitivity maps in x, as denoted by $\mathcal{S}$. All coil images are then masked to a given field of view (M), Fourier-transformed ($\mathcal{F}$), and sampled (P) at each echo.

Fat and R_2^* mapping is achieved via joint estimation of the unknown x, i.e. minimizing the least square difference between the measured data y and the forward model under regularizations based on *a priori* knowledge of unknowns,

$$\begin{aligned} &\text{minimize } \|y - F(x)\|_2^2 + \lambda_1 \|\mathcal{W}(E_1 x)\|_1 + \lambda_2 \|\mathrm{TV}_t(E_2 x)\|_1 + \lambda_3 \|x\|_2^2 \\ &\text{subject to } R_2^* \geq 0 \end{aligned} \quad (4)$$

We applied Wavelet regularization and temporal total variation (TV) regularization on the physical parameters in Equation (2), ℓ^2 regularization on x, and non-negativity constraint on R_2^*.

EXPERIMENTS

7 subjects (age 28 ± 7, 1 male) with body mass index 21.4 ± 2 kg m^{-2} participated in this study with written informed consent before MRI in compliance with the regulations established by the local ethics committee. Detailed parameters are flip angle 5^o, voxel size $1.6 \times 1.6 \times 5$ mm^3, echo times (TE) 1.31, 2.54, 3.77, 5.00, 6.23, 7.46, 8.69 ms and repetition time (TR) 9.89 ms. A total scan time of 15 s without breath hold.

RESULTS & DISCUSSION

Figure 2 shows reconstruction results of two subjects from the proposed MERLOT, and the Siemens reference method, respectively. Clearly, Subject #7 shows elevated FF valuess in the liver from both methods, indicating **fatty liver disease**. R_2^* is a physical quantity linearly proportional to **iron concentration**. R_2^* values of both subjects are in the normal range.

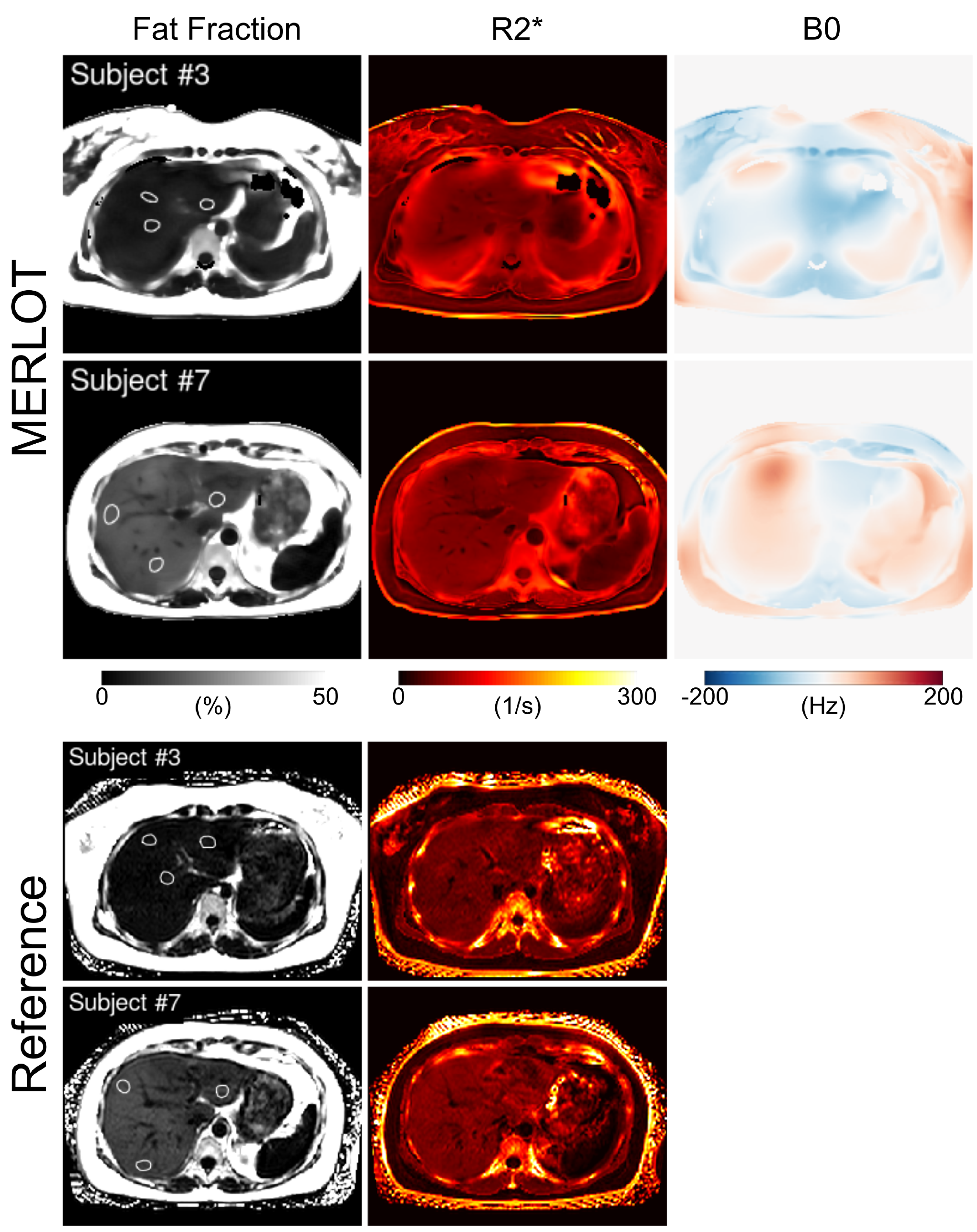

Figure 2: (Top) Fat fraction (FF), R_2^* and B_0 maps from the proposed MERLOT method. (Bottom) Reference FF and R_2^* maps from Siemens.

CONCLUSION

A free-breathing liver fat and R_2^* mapping technique has been developed and evaluated in subjects with fatty liver disease.

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