Blood-Suppressed T2* Mapping in Liver with Motion Sensitized Driven Equilibrium (MSDE)

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Introduction. In liver imaging, T2* mapping assesses iron loading[1,2], which is relevant in thalassemia, hereditary hemochromatosis, and sickle cell disease[3]. However, with no innate flow suppression, multi-echo spoiled gradient echo (SPGR) sequences suffer from artifacts originating from flowing blood spins. This work combines a motion-sensitized driven equilibrium (MSDE) preparation[4] with multi-echo SPGR to suppress the blood signal intensity in breath-hold T2* mapping of the liver.

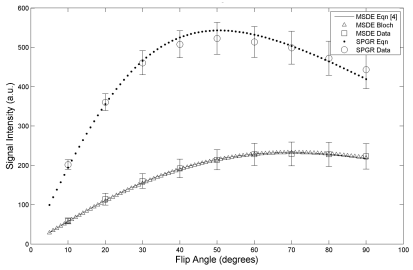

Fig. 1. Experimental and simulated signal intensity of the SPGR sequence, with and without the MSDE preparation, as a function of flip angle. The maximal signal is achieved at lower flip angles for the SPGR acquisition versus the MSDE-SPGR acquisition.

Methods. MSDE preparation consists of a non-selective 90° pulse, a pair of gradient lobes around a non-selective 180° pulse, and a -90° driven equilibrium pulse, requiring a total time of τ_{prep}. The gradients around the 180° pulse of width δ, strength G, and separation Δ add intravoxel incoherent motion sensitivity to all spins[5]. The field of speed (FOS) is the velocity at which a spin will attain a 2π phase accrual[6]. By defining $E_b=e^{-bD}$, $E_{prep}=e^{-\tau prep/T2}$, $E_\tau=e^{-\tau/T1}$, and $E_{end}=e^{-\tau end/T1}$, where $TR=\tau_{prep}+\tau(n)+\tau_{end}(n)$, the analytical formula of the steady state magnetization S_{SS} was calculated as:

$$S_{SS} = M_0 \cdot \frac{(1-E_{end(n)})\cdot E_{prep}E_{\tau_{(n)}}E_b + (1-E_{\tau(n)})}{1-\cos(\alpha)\cdot E_{end(n)}E_{prep}E_\tau E_b}\sin(\alpha)\cdot e^{-TE/T}$$

. This is a modified form of the well-known SPGR steady state signal equation. The MSDE-prepared multi-echo SPGR sequence was implemented on VB17 Siemens 3T Trio (Siemens Healthcare, Erlangen Germany). First, the angle that gives maximal signal in the MSDE-SPGR sequence was optimized, with measurements of the liver at flip angles from 10 to 90° (results in Fig 1). Secondly, the optimization of blood suppression was performed, by changing the MSDE preparation gradients to yield six values of FOS (∞ **,** 100, 75, 50, 30, and 15 cm/s, results in Fig 2) resulting in b-values up to 0.38 s/mm^2. A FOS of ∞ corresponds to a non-MSDE prepared SPGR acquisition. T2* maps in five healthy livers were acquired using a FOS of 30cm/s, taking 10 echoes in a 20s breath-hold and fitting to an exponential decay, $S(TE)=\rho_{app}[\exp(-TE/T2^*)]+C$, where ρ_{app} is proportional to the apparent spin density and C reflects a rectified noise floor.

T2* values (ms) in Liver with increasing Blood Suppression						
FOS (cm/s)	∞ (SPGR)	100	75	50	30	15
b (s/mm^2)	0	0.014	0.026	0.048	0.12	0.38
Small ROI	14.7±0.6	15.0±0.7	14.9±0.7	14.9±0.7	14.9±0.7	14.7±0.6
Liver ROI	19.4±10.7	18.6±7.7	18.5±8.2	15.8±5.8	15.6±6.4	15.2±6.0

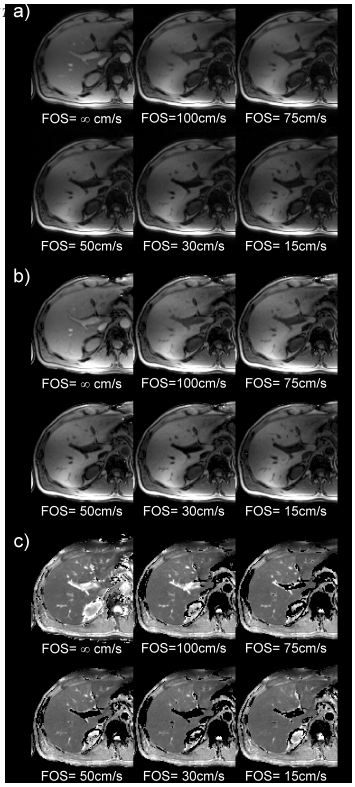

Fig. 2. Liver images with increasing flow suppression. a) The first echo image, b) resultant apparent proton density, and c) T2* maps in. Blood in the descending aorta is suppressed even at FOS=100cm/s, but slower flowing blood in the portal vein and minor liver vessels are significant until a FOS of 30cm/s.

Results. The analytical solution for the steady-state signal as well as the Bloch simulations and in vivo data show an additional signal decay, due to diffusion-weighting and T2 decay during the preparation, in the MSDE-SPGR sequence, compared to the SPGR sequence (Fig. 1). Optimal flip angles for the MSDE-SPGR sequence occur at values > 60°. Optimization of the blood suppression in the liver (Fig. 2a, first echo images) shows that the rapid flow of the descending aorta is suppressed even with a FOS of 100cm/s, but the portal vein and smaller vessels are only suppressed by a FOS of 30 cm/s or less. The efficacy of the blood suppression can be summarized in Table 1, which compares T2* values found in a small ROI in the liver that carefully excludes any possible vessels with a large ROI covering the majority of the liver, but excluding the portal vein. Without blood suppression (FOS=∞), a higher T2* is measured, with greater variation over the liver due to the longer T2* of blood than liver tissue (Table 1). The variation reduces, and the mean of the large ROI approaches that of the small, vessel-excluding ROI. With blood suppression, the T2* has reduced slightly, with a lower standard deviation. Values of T2* found in all five subjects is reported in Table 2. In all cases, flow suppression reduced the variation in the T2* found across the liver.

T2* values (ms) in Liver		
FOS (cm/s)	∞ (SPGR)	30
Subject 1	20.1 ± 11.4	17.9 ± 8.0
Subject 2	16.9 ± 5.3	16.2 ± 2.5
Subject 3	13.0 ± 7.0	11.5 ± 4.3
Subject 4	14.3 ± 6.4	12.7 ± 3.9
Subject 5	18.1 ± 12.6	14.9 ± 4.7

Conclusions. This work demonstrates the acquisition of T2* maps in the liver with an effective and robust blood suppression, MSDE.

References: [1] Positano, et al. MRI, 2009. **27**(2): 188-197. [2] Virtanen, et al. MRI, 2008. **26**(8): 1175-1182. [3] Gandon, et al. Radiology, 1994. **193**(2): 533-8. [4] Pell, et al. MRM 2003. **49**(2): 341-350. [5] Stejskal, E. and J. Tanner, J Chem Phys, 1965. **42**: 288-292. [6] Nguyen, et al. J Magn Reson Imaging, 2008. **28**(5): p. 1092-100.