Single Breath-Hold 3D Radial Imaging for R_2^* and Fat Fraction Quantification in the Liver

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Target audience: Scientists and clinicians interested in quantitative biomarkers of liver fat content and iron overload.

Purpose: In the presence of hepatic iron overload, quantification of R_2^* and fat fraction (FF) is challenging due to rapidly decaying signal. A very short first echo time (TE) and echo spacing (ΔTE) are necessary to improve the SNR performance of both R_2^* and FF estimation in the high R_2^* regime (iron overload)[1]. This is particularly true at 3T, where the R_2^* signal decay rate is approximately twice that at 1.5T. With conventional Cartesian imaging, the minimum TE is typically 700-800µs. However, much shorter echo times can be obtained with center-out radial sampling, where data acquisition starts immediately after excitation. In this work we propose a single-breath-hold, 3D radial acquisition with angular undersampling, chemical shift encoding and iterative parallel imaging reconstruction for R_2^* and FF quantification in the liver. R_2^* and FF measurements were performed in phantoms, healthy volunteers and patients with severe iron overload and compared to R_2^* and FF values obtained with a hybrid sampling scheme and conventional Cartesian sampling.

Methods: All images were acquired in a single breath-hold at 3T (GE MR750, Waukesha, WI) using a 32-channel, phased-array surface coil for reception.
Pulse sequences: **(a)** Multi-echo, 3D Radial (3DR), RF-spoiled, gradient-echo acquisition. Six center-out echoes with fly-back gradients (TE=330µs; ΔTE=720µs); FOV = 40cm; matrix size = 128^3 ($3mm^3$ isotropic resolution); receiver bandwidth (rBW) = ±125kHz; TR = 6.2ms; flip angle = 3°; number of projections = 3000.
(b) 3D multi-echo, RF-spoiled, gradient-echo acquisition with in-plane radial sampling and Cartesian through-plane slice encoding (Stack Of Stars, SOS). Six center-out echoes with fly-back gradients (TE=330µs; ΔTE=720µs); FOV = 40cm; slice thickness = 10mm; matrix size = 128×128×24; rBW = ±125kHz; TR = 6.2ms; flip angle = 3°; number of projections per $k_z = 200$.
(c) 3D, multi-echo, spoiled gradient echo acquisition with Cartesian sampling (3DC) and 2×2 parallel imaging acceleration. Six echoes with fly-back gradients (TE=1.2ms; ΔTE= 1ms) in two interleaves (ETL = 3); FOV = 40cm; slice thickness = 8mm; matrix size = 256×144×24; rBW = ±125kHz; TR = 5.4ms; flip angle = 3°.
Reconstruction: Iterative SENSE[2] after gridding and ARC[3] (Accelerated Reconstruction for Cartesian sampling) were used to reconstruct 3DR/SOS and 3DC, respectively. Complex water-fat separation with simultaneous R_2^* estimation[4] was performed using a Graph Cut[5] algorithm for field map estimation.
Phantom experiments: R_2^* measurements were performed in vials with increasing iron concentration (0, 25, 50, 75, 100mg Fe/l). FF measurements were obtained in a water-fat phantom built according to Hines[6]. Single-voxel MRS[7] was used to obtain reference values for FF (MRS FF).
Healthy volunteers: R_2^* and FF maps were acquired in 6 healthy volunteers using 3DR, SOS and 3DC.
Iron overload patients: Two patients with severe iron overload were scanned with 3DR and 3DC. MRS was performed in the right lobe of the liver (segment 6 or 7). IRB approval and written informed consent from all subjects were obtained.

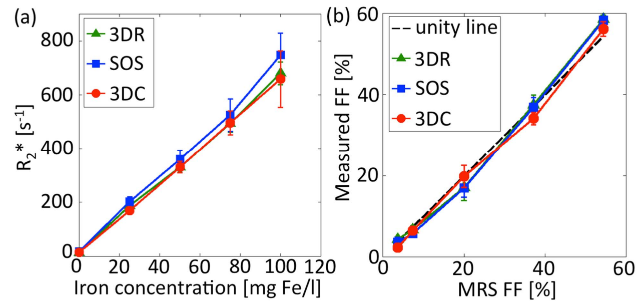

Figure 1: Phantom experiments. R_2^* (a) and FF (b) measurements obtained with 3DR, SOS and 3DC.

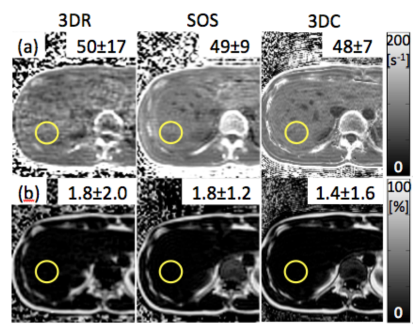

Figure 2 (above): R2* (a) and FF (b) maps acquired in a healthy volunteer with 3DR, SOS and 3DC with representative ROIs.

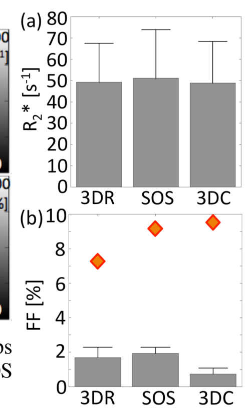

Figure 3 (right): Mean and std. deviation of R_2^* (a) and FF (b) measurements in 6 healthy volunteers. Note outlier with ~9% FF in (b).

Results and discussion: *Phantom experiments*: There was a linear relationship between R_2^* and iron concentration irrespective of the acquisition strategy (Fig. 1a). Similarly, there was good agreement between FF as measured by 3DR, SOS and 3DC and the reference MRS FF (Fig. 1b).
Healthy volunteers: Good quality R_2^* and FF maps were obtained with all techniques (Fig. 2). There was no statistically significant difference in R_2^* and FF when different pulse sequences were used ($p>0.05$; paired t-test; Fig. 3).
Iron overload patients: In both cases, 3DR and 3DC gave similar R_2^* values. In one of the two patients, R_2^* was ~539 1/s (Fig. 4a). MRS gave a 13% FF and 3DR showed close agreement (measured FF = 14.1%; pixel-wise standard deviation = 13%). However, 3DC gave an apparent FF of 0.4% (pixel-wise standard deviation = 43%), suggesting that the longer TEs of 3DC can lead to erroneous FF estimates.

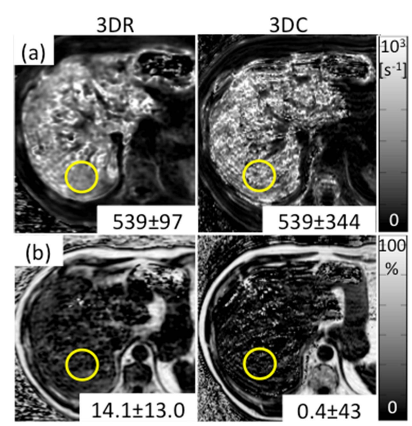

Figure 4: R_2^* (a) and FF (b) in a patient with severe iron overload.

Conclusions: We have shown that 3DR in a single BH can be used for hepatic R_2^* and FF quantification and that this technique could be particularly useful in cases of severe iron overload.

References: [1] Hankins J.S. Blood 2009; 113: 4853; [2] Pruessmann K.P. MRM 2001; 46:638; [3] Brau A.C. MRM 2008; 59:382; [4] Yu H. JMRI 2007; 26(4): 1153; [5] Hernando D. MRM 2010; 63: 79; [6] Hines C.D. MRM 2009; 30:1215; [7] Hamilton G. JMRI 2009; 30: 145.