Qualtification of rapid decay species with short TE spin echo sequence

Eamon K Doyle[1,2], Jonathan M Chia[3], Krishna Nayak[1,4], and John C Wood[1,2]

[1]*Biomedical Engineering, University of Southern California, Los Angeles, CA, United States,* [2]*Cardiology, Children's Hospital of Los Angeles, Los Angeles, CA, United States,* [3]*Philips Healthcare, Cleveland, OH, United States,* [4]*Electrical Engineering, University of Southern California, Los Angeles, CA, United States*

Target Audience Clinicians and engineers interested in imaging and quantifying short T_2 species such as iron-loaded tissues.

Purpose Estimation of transverse relaxation rate (R_2) is an important clinical tool for quantifying iron overload in tissues. In heavily iron loaded tissue, R_2 and R_2^* relaxation rates, $1/T_2$ and $1/T_2^*$ respectively, can be too rapid for standard spin and gradient echo techniques to accurately measure, particularly at high field.[1] R_2 rises less quickly than R_2^* with iron burden and scales less steeply with field strength, making it attractive for estimating high iron loads at 3T. We propose a low-flip angle spin echo sequence with echo times as low as 1.43 ms for liver iron quantification at 3T, quantifying R_2 up to 1200 Hz.

Methods Single spin echo scans of $MnCl_2$ phantoms with varying concentration to simulate iron-loaded livers were acquired using a 3T MR system (Acheiva, Philips Healthcare, Best, The Netherlands) with an 8-channel SENSE-XL-Torso coil. The pulse sequences used a 45° tip pulse based on the Tukey window function and a 45° hard spin echo pulse. Echo times of [1.43,1.52, 1.81,1.9,2,3,4,5,6,8,10,12,15] ms were gathered in vials of [0,0.5,0.75,1,1.5,2,2.5,3.5,5,8,12,16] mM $MnCl_2$. Additional sequence parameters included TR=750 ms, BW=3646 Hz/pixel, NSA=1, matrix=128x95, and voxel size=3.71x3.71x15 mm. Per-voxel R_2 estimates were made in MATLAB (Mathworks, Natick, MA) with internally developed software using a mono-exponential plus constant model and a constrained nonlinear least square algorithm. Estimated R_2 values were constrained to values of 0-2000 Hz based on the range of relaxation rates represented in the phantom. Voxels from each vial were averaged to obtain a single relaxation rate estimate for each sample.

Results Using the short echo time sequence, we are able to achieve reliable estimates of $MnCl_2$ concentration based on R_2 relaxation rate. Figure 1 demonstrates successful calibration of the manganese chloride relaxation rate to concentration from 0.5 to 12 mM $MnCl_2$, predicting R_2 values ranging from 80 Hz to 1200 Hz. There is generally good R_2 agreement for all vials up to 12 mM $MnCl_2$. R_2 estimation in higher concentrations would require significantly decreased spatial resolution.

Discussion This pulse sequence shortened TE by using an imperfectly slice selective Tukey pulse capable of achieving 45° excitations in 0.22 ms. With the Tukey pulse and paired 45° excitations, we achieved 1.43 ms echo times, allowing R_2 quantification more than double the highest liver R_2 values expected at 3 Tesla.[2] Other paired pulse combinations such as 60°-60° and 120°-120° were tested as well as unmatched pulses including 50°-33° (results not shown); the 45°-45° pulse set showed the best balance between short echo time, image quality, and relaxation estimate accuracy. Furthermore, experiments with echo times as short as 1.22 ms were performed (data not shown), allowing quantification of the 16 mM $MnCl_2$. However, an increased minimum echo time of 1.43 ms was ultimately chosen to improve resolution and image quality while still being capable of capturing the entire clinically relevant range of decay rates. While the Tukey pulse provides an imperfect slice profile, wide slice gaps are possible in a large organ like the liver. The Tukey pulse was ultimately selected for time efficiency; combined with smaller flip angles, the Tukey pulse reduces the time required to achieve the desired flip angle, lowering the TE.

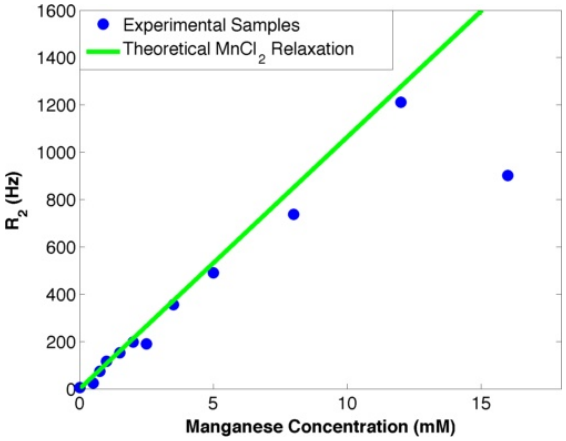

Figure 1-Relaxation rate vs. manganese concentration demonstrates that the propsed sequence can quantify a clinically relevant range of R_2 values.

The echo times show a nearly linear relationship as expected from previous experiments using $MnCl_2$. The concentration-based relaxivity enhancement fit shows that $R_2[Hz] = 117 \times MnCl_2\,[mM]$, which is 1.46 times larger than the concentration-based enhancement coefficient of 80 at 1.5T [2]. A simulated comparison of susceptibility-mediated losses in iron-loaded liver at 1.5 and 3T shows that doubling the field strength increases the relaxivity enhancement by a factor of 1.4.[2] Despite relaxation being mediated by dipole-dipole interactions in $MnCl_2$, the field-dependent relaxivity enhancement appears to follow a similar trend compared to iron.

Conclusion Conventional 90-180 spin-echo methods fail in patients whose liver R2 values exceed 160 Hz because of inadequate sampling of the decay curve. Our present data suggest that we can use a low-flip short TE spin echo method to estimate liver iron content over the entire clinically relevant range (0-60 mg/g) with 3T scanners. Future work will focus on testing this sequence in-vivo, and evaluating other families of functions, including Kaiser-Bessel and Dolph-Chebychev functions, that exhibit better side-lobe performance for modest prolongation of achievable echo times. We are also exploring multiple echo signal behavior to determine whether it can be used to better probe tissue iron distribution. Further, we expect additional optimizations to lower minimum echo time may allow estimation of faster signal decay than demonstrated here.

References

[1] Ghugre N. Calibration of Iron-Mediated MRI relaxation by Monte Carlo Modeling. Los Angeles: University of Southern California; 2008. 159 p.

[2] Ghugre, N. R., Doyle, E. K., Storey, P., & Wood, J. C. (2014). Relaxivity-iron calibration in hepatic iron overload: Predictions of a Monte Carlo model. MRM, doi:10.1002/mrm.25459