B1+ inhomogeneity effects on clinical liver iron quanitification at 1.5T and 3T

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Introduction Spin-echo MRI-based estimates of R_2 are used clinically to track liver iron concentration [1,2] at 1.5T and 3T. At 3T, B1 transmit (B_1^+) inhomogeneity can be quite large; however, to our knowledge, the effects of B_1^+ inhomogeneity on R_2 quantitation have not yet been explored. In the past, Monte Carlo simulations have been used to accurately characterize the relationship between MRI-measured R_2 and liver iron concentration [3]. In this work, we adapt these models to include B_1^+ inhomogeneity. We demonstrate that R_2 estimates will experience a systematic bias in the presence of B_1^+ inhomogeneity, and propose possible improvements to in-vivo imaging procedures at both 1.5 and 3T.

Methods Statistical models of liver tissue were used to generate 3D blocks of liver tissue with iron deposits of varying concentration and size. Magnetic field maps of B_0 disturbances created by liver iron ferromagnetism were created from the iron distribution with 0.5 μm isotropic resolution. Proton diffusion paths were generated using a Gaussian distribution with cell and tissue boundary constraints. A multi-echo spin echo sequence was simulated by solving the Bloch equations during each radiofrequency transmission. Proton dephasing was mediated by the magnetic field maps generated from the tissue blocks. Transmission bandwidth was assumed to be infinite, producing instantaneous excitations sensitive to B_1^+ and instantaneous refocusing pulses insensitive to B_1^+. Simulations were repeated for seven B_1^+ scales from 0.9 to 1.1, eight iron loads from 8 to 50 mg/g, and 1000 spins per scenario.

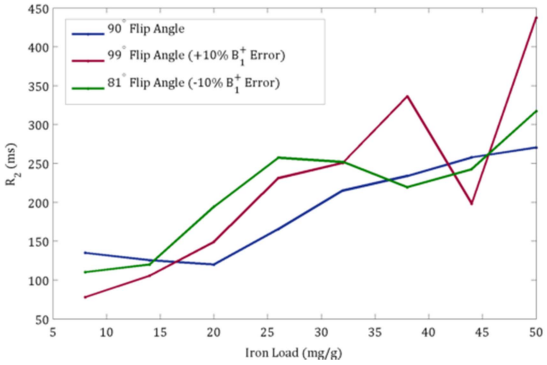

Figure 1 - Comparison of R_2 values estimated from simulation runs showing that the ideal flip angle case produces lower R_2 values than experiments with B_1^+ inhomogeneity

Results Table 1 demonstrates the Bland-Altman comparison different amounts of B_1^+ inhomogeneity to the homogenous case. The simulations suggest that B_1^+ deviation increased R2 estimates by roughly 15.6% (standard error 4.2%, p=0.03), with the error trending upward with larger flip angle deviation. Figure 1 illustrates the relationship between R_2 and iron load. The +10% and -10% B_1^+ inhomogeneity and shows the trend of both to over-estimate R_2, resulting in iron load overestimation compared to the ideal case. B_1^+ inhomogeneity measured using the double angle method with an excitation angle of 60° in a healthy volunteer showed in-vivo flip angles ranging from 40° to 75°.

Discussion The study suggests that B_1^+ inhomogeneity may confound liver iron quantification at 3T, even if limited to errors in the excitation pulse. This may be due to the decreased amplitude of transverse magnetization leading to an underestimation of T_2 during curve fitting, but the mechanism of this effect needs further exploration. The present work was limited, in part, by the small simulation size (1000 protons) but also by the intrinsic stochastic nature of liver iron distribution captured by simulations. Since iron-particle size and distribution vary with each simulation, the "true" calibration curve at any flip angle is not a straight line, but a distribution with a coefficient of variation on the order of 20% (2), comparable to clinically observed variability (1). This intrinsic variability allows the observations to be generalized to the general population, but requires simulating many patients at each measurement condition to reduce physiologic noise. In spite of the short TR used for B_1^+ mapping, the liver shows significant flip angle inhomogeneity, suggesting that B_1^+ inhomogeneity will play a role in iron quantification. Additional simulations including large B_1^+ inhomogeneity and the effects of refocusing pulse imperfections will be generated to better characterize the source of systematic underestimation and to improve quantitation of the effect size. More robust B_1^+ mapping techniques will be used to further characterize inhomogeneity in the liver.

	B_1^+ Inhomogeneity							
Iron load	0.9	0.933	0.967	1.0	1.03	1.07	1.1	R_2 Value(ms)
8 mg/g	-42	5	-30	0	-32	-37	-19	135
14 mg/g	-16	43	0	0	18	40	-4	125
20 mg/g	24	4	33	0	24	45	62	120
26 mg/g	39	7	7	0	16	-4	55	166
32 mg/g	17	97	-34	0	-26	-7	17	215
38 mg/g	44	17	31	0	-12	12	-6	234
44 mg/g	-23	33	-17	0	68	30	-6	258
50 mg/g	62	74	69	0	30	16	17	270

Table 1 – % error of estimated R_2 value at a given B_1^+ scale from R_2 estimation from 90° excitation.

References

[1]Wood, J and Ghugre. Blood, 106:4, p1460-1465 [2]Sirlin, C and Reeder, S. Mag Reson Imaging Clin N Am, 18:3, p359-ix. [3]Ghugre, N and Wood, J. MRM, 65:3, p837-847