Spin echo B1+ mapping in high susceptibility tissues

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Target Audience Clinicians and engineers interested in B1+ mapping in high susceptibility tissues.

Purpose Estimation of B1+ transmit amplitude is important for reconstruction of many image types in MRI and for correcting for transmit inhomogeneities in multi-transmit systems. In high susceptibility tissues with rapid decay rates, phase based and magnitude based methods employing gradient echo scans can fail. We propose a signal intensity-based method employing short TE spin echoes to increase the SNR and decrease susceptibility-mediated losses. We demonstrate imaging improvements in samples with R_2 relaxations as short as 1500 Hz to exceed the clinical requirements for imaging liver iron loads [1].

Methods Two single-slice, single-spin echo scans were acquired in a Ferriheme-in-Agar phantom using a 3T MR system (Acheiva 3T, Philips Healthcare, Best, The Netherlands) with an 8-channel XL-Torso coil. The pulse sequences used a 60° and 120° excitation pulses based off of a Tukey window (20 samples, r=0.50) and a 45° echo hard pulse to decrease the echo time; other parameters include TE=2.11 ms, TR=285 ms, BW=4629 Hz/pixel,NSA=1, matrix=84x64, voxel size=5.6x5.6x25.0 mm. The phantom vials were constructed with 10% agarose solution combined with [0.042, 0.083, 0.21, 0.42, 0.83, 1.25, 1.67] mg Ferriheme/g Agarose solution and relaxation rates measured in a 1.5T relaxometer. B1+ maps were estimated using a derivation identical to the dual angle method with internally developed MATLAB (Mathworks, Natick, MA) software.[2] Separately, a 3D gradient echo dual TR B1+ map was obtained on the same phantom with TE/TR1/TR2 =0.71/20/100 ms, NSA=1, BW = 7593 Hz/pixel, matrix = 64x53, voxel size =8.28x10.08x10 mm.

Results Using the dual angle spin echo method, the estimated B1+ map showed improved image quality in all vials and improved B1 map stability in all but the vial with the highest concentration of Ferriheme. In-vial estimates for lower Ferriheme concentrations matched between the two methods (figure 1); comparison in the higher concentration vials was not possible in the dual TR images due to susceptibility induced image degradation. Figure 2 demonstrates that the signal-to-noise ratio (SNR) was comparable in low concentration vials for both methods but the spin echo method showed improved SNR in the higher concentration vials, indicating improved B1 mapping in high susceptibility environments.

Discussion These results suggest that B1+ mapping in high susceptibility tissues may be improved using spin echo based methods rather than phase based methods or gradient echo imaging. Bloch-Siegert shift B1 mapping cannot be used due to off resonance in the liver samples reaching up to 1700 Hz in heavily loaded patients.[3] Additionally, liver decay rates can be many times shorter than the RF pulses required for Bloch-Siegert mapping; the signal will decay before the RF pulse has finished. Our results further validate that achieved flip angle in iron-loaded tissues may be low, whether due to B1 variation or some other reason for underexcitation. Previous simulation results demonstrated that B1+ inhomogeneity could cause quantification errors in liver iron overload, supporting the idea that a B1+ mapping method robust to high susceptibility will be most effective at diagnosing iron-loaded patients[4].

With a Tukey pulse and double angle excitation scheme, we achieved 1.75 ms echo times, allowing B1+ mapping in samples with R_2 values of 1500 Hz. Image quality in the spin echo B1 map was significantly higher than the gradient echo based map. B1+ estimates in even the low concentration vials are qualitatively lower than expected in both maps, which may be a result of under excitation due to high off resonance.

Conclusion We present a spin-echo method capable of performing B1 mapping robust to high susceptibility and rapid T_2 decay. Further tests will be necessary to ensure that B1+ estimates are not artificially depressed due to insufficient pulse bandwidth or excessive pulse duration relative to the T_2 decay rate.

References

[1] Ghugre N. Calibration of Iron-Mediated MRI relaxation by Monte Carlo Modeling. Los Angeles: University of Southern California; 2008. [2]C. H. Cunningham et.Al, "Saturated double-angle method for rapid B1+ mapping," Magnetic Resonance in Medicine, vol. 55, no. 6, pp. 1326–1333, 2006.

[3]V. L. Yarnykh, "Actual flip-angle imaging in the pulsed steady state: a method for rapid three-dimensional mapping of the transmitted radiofrequency field," Magn Reson Med, vol. 57, no. 1, pp. 192–200, Jan. 2007.

[4]Doyle, et. Al., "B1+ Inhomogeneity Effects on Clinical Liver Iron Quanitification at 1.5T and 3T," ISMRM, Salt Lake City, UT, 2013.
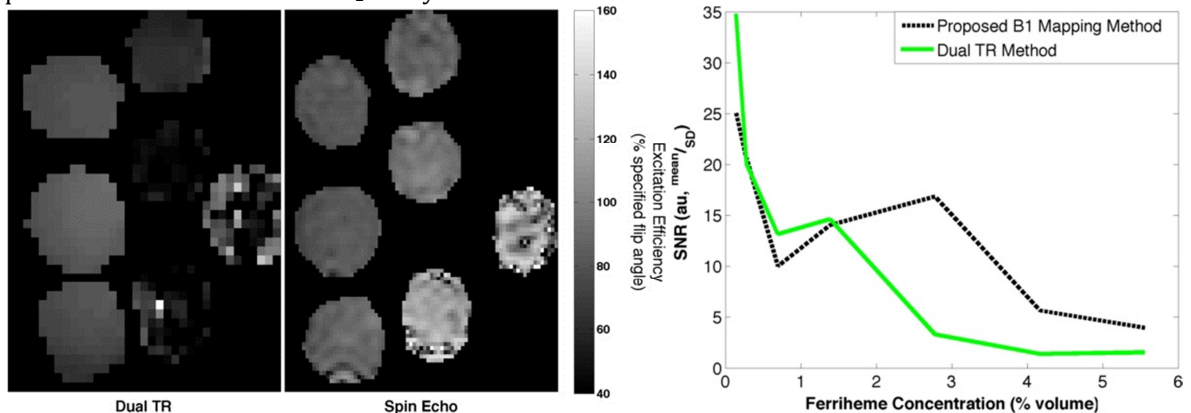
Figure 1 - Image of B1+ maps. The dual TR method [left] shows significant degradation in the highest concentration vials. High concentration vials are reproduced effectively using spin echo method [right].

Figure 2 - Demonstration of comparable SNR performance of proposed B1+ mapping method relative to dual TR mapping in low concentration vials and superior performance in high-susceptibility, fast T_2 decay vials.