Improved adiabatic inversion design for myocardial T1-mapping

Peter Kellman[1], Daniel A Herzka[2], and Michael Schacht Hansen[1]

[1]*NHLBI, NIH, Bethesda, MD, United States,* [2]*Biomedical Engineering, Johns Hopkins School of Medicine, Baltimore, MD, United States*

Introduction: T1-mapping in the myocardium provides a means for quantifying and detecting edema and/or fibrosis with elevated T1. Look-Locker methods such as MOLLI [1] based on inversion recovery rely on ideal inversion. However adiabatic inversion pulses used to mitigate inhomogeneity of transmit B1 field strength do not achieve perfect inversion as a result of transverse relaxation (T2) during the pulse. Imperfect inversion leads directly to a T2-dependent error in T1. An improved adiabatic inversion pulse optimized for myocardial T1-mapping was designed and evaluated experimentally.

Methods: The inversion factor was calculated for several adiabatic inversion designs [2] using Bloch equations. Optimization was performed by brute force over a range of design parameters. The design space was ±150 Hz and 25% variation in B1 field strength with a peak amplitude constrained to be less than 0.015 mT. The existing sequence used a hypersecant design. The design considered hypersec (HS1, HS4, HS8) and tan/tanh pulses over the range T1=400-1600 ms and T2=45-250 ms. Design optimization included the pulse duration, frequency sweep bandwidth, and shape parameters. Experimental validation used a set of $CuSO_4$ doped agar gel phantoms with varying concentrations with T1 and T2 in the expected range for myocardium. Measurements were acquired using an inversion recovery GRE sequence with TR=10s at multiple inversion times (TI). The T1 and the inversion factor were estimated using a 3-parameter fit, i.e., $M(t) = M0 (1 - (1+b) \exp(-t/T1))$, which assumes complete relaxation (TR<<T1) and the inversion factor is denoted by b. T2 was measured using exponential fit to SE measurements with TR=10s and varying echo times (TE). Transmit field strength was measured using the dual flip angle method to ensure the correct transmit level, and off-resonance was measured using a multi-echo GRE field mapping sequence to ensure the data were acquired on-resonance.

Results: The adiabatic condition achieves independence of B1 transmit field strength but does not achieve perfect inversion (Fig 1). The inversion factor is dependent on both T1 and T2 (Fig 2). The response vs B1 and off-resonance is graphed for a 10.24 ms hypersecant designed pulse (fmax=535 Hz, beta=3.42) used in the product cardiovascular sequences tested (Siemens Medical Solutions, Erlangen, Germany) and the optimized 2.56 ms tan/tanh (fmax=9.5kHz, zeta=10, tan(k)=22) (Fig. 3). Note the contours which plot level of inversion; the optimized pulse achieves improved inversion over the design region indicated by the green box.The measured inversion factor is greatly improved for the tan/tanh design (Fig. 4) reducing the uncorrected error in myocardial T1 from approx. 10% to <5%.

Discussion and Conclusions: Imperfect adiabatic inversion results from transverse relaxation (T2) and may be improved by using a shorter duration pulse with optimized parameters. Due to peak power constraints, a tan/tanh design was found to achieve better inversion performance than hypersec with the same duration. Reduced dependence on both T1 and T2 facilitate a calibrated correction of T1-estimates to further reduce the T1-error observed during T1-mapping due to imperfect inversion.

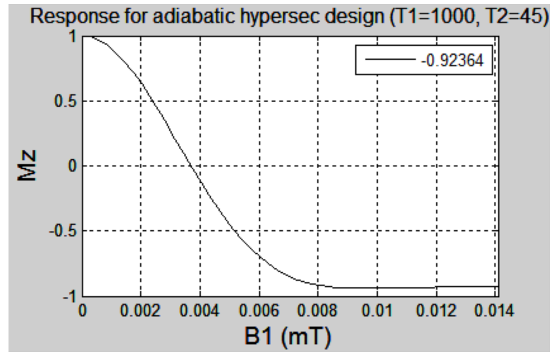

Figure 1. Response of hypersec inversion pulse illustrating imperfect inversion due to T2 relaxation.

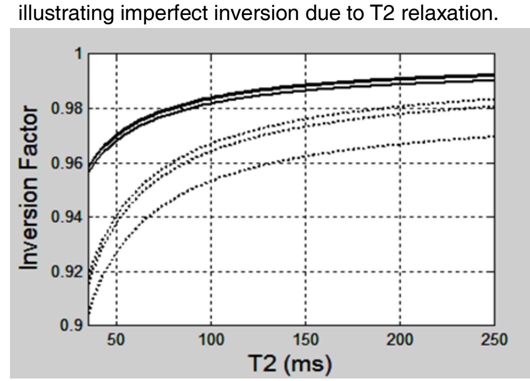

Figure 2. Dependence of adiabatic inversion factor on T2 for 10.24 ms hypersec (dashed) and 2.56 ms tan/tanh (solid) designs for T1 = 400, 1000, & 1600 ms.

References: [1] Messroghli DR, et al. J Magn Reson Imag 2007, 26:1081–6. [2] Hwang TL, et al. J Mag Reson 1998;133(1):200-3.

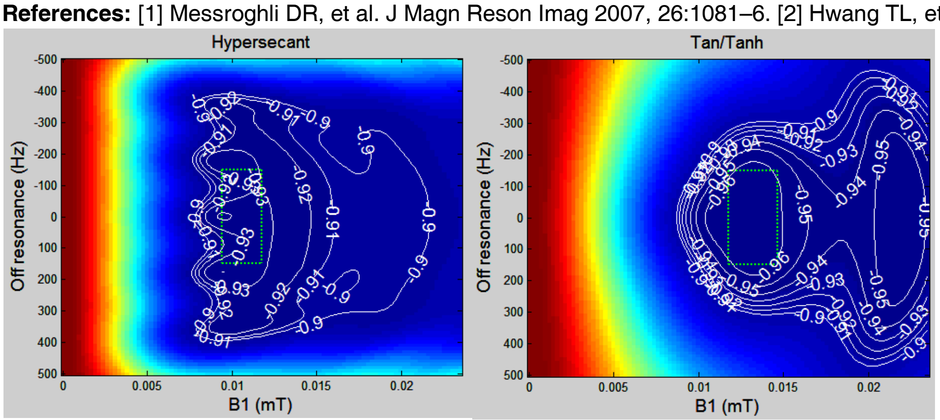

Figure 3. Response of adiabatic IR for T1=1000ms/T2=45ms using hypersec (left) and tan/tanh (right) designs. Design region is indicated by dotted green box (25% amplitude range, ±150 Hz).

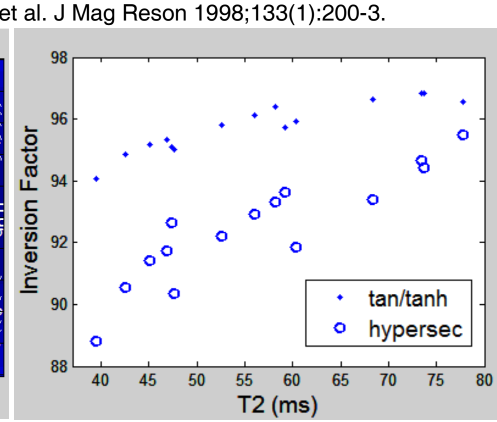

Figure 4. Measured inversion factor vs T2 (various T1) for 2 adiabatic inversion designs.