Improved adiabatic inversion design for myocardial T1-mapping

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INTRODUCTION

Purpose:

- To evaluate the error in T1-estimates using inversion recovery based T1-mapping [1] due to imperfect inversion
- Perform a systematic study of adiabatic inversion pulse designs in order to maximize inversion efficiency for values of transverse relaxation (T2) in the myocardium subject to a peak power constraint.

METHODS

- inversion factor calculated [2] using Bloch equations for adiabatic full passage waveforms:
  - ❑ hyperbolic secant (HSn)
  - ❑ tangent/hyperbolic tangent (tan/tanh)
- design optimization:
  - ❑ pulse duration
  - ❑ frequency range
  - ❑ shape parameters
  - ❑ peak amplitude
- brute force search maximized the inversion factor over a specified range of amplitude and off-resonance
- validated using phantom measurements
- empirical correction for imperfect inversion

THEORY

$M(t) = M0^* - (\delta\, M0 + M0^*) \exp(-t/T1^*)$	inversion recovery
$\delta = \delta\,(T1,T2)$	inversion factor
$M(t) = A - B \exp(-t/T1^*)$	3-parameter model
$T1 = (B/A-1)\, T1^*$	MOLLI estimate with Look-Locker correction
$T1corrected = (B/A-1)\, T1^* / \delta$	estimate corrected for imperfect inversion

RESULTS

The tan/tanh adiabatic pulse was found to outperform HS designs, and achieve an inversion factor of 0.96 within ±150 Hz over 25% amplitude range with 14.7 μTesla peak amplitude. T1-mapping errors of the selected design due to imperfect inversion was approx. 4% and could be corrected to <1%.

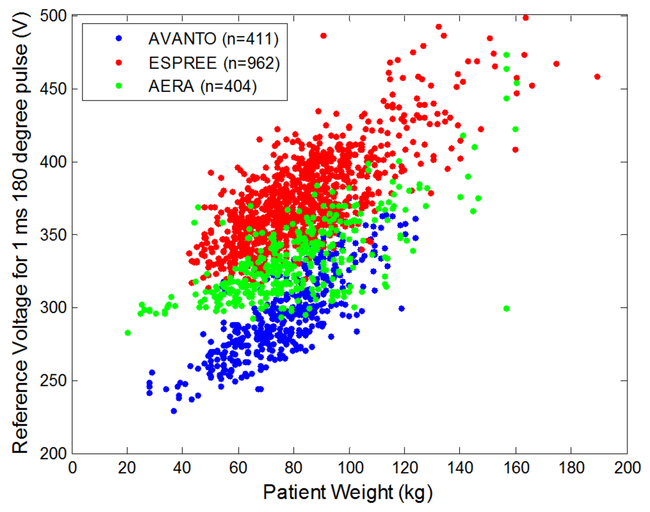

Figure 1. Transmit amplifier reference voltage as measured by scanner flip angle calibration required to achieve a 180 degree flip angle using a 1 ms square pulse for a range of subject loading for 3 MR systems. These voltages correspond to a 11.7 µT B1+ field..

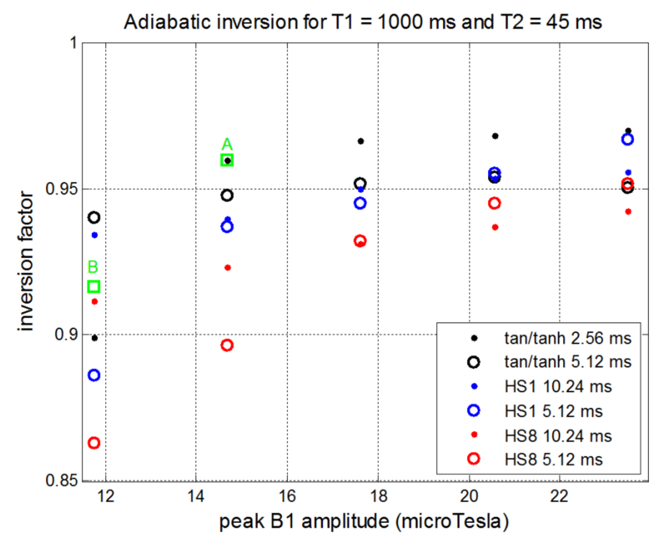

Figure 2. Inversion factor vs peak B1 amplitude calculated for various adiabatic inversion pulse designs. Designs marked by green box A and B correspond to the T1-mapping optimized tan/tanh and the HS1 used on the system product sequences, respectively.

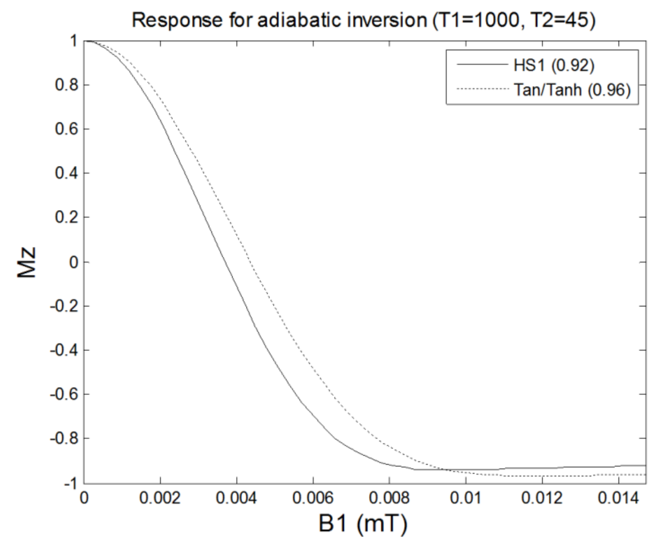

Figure 3. Responses of inversion pulse illustrating imperfect inversion due to T2 relaxation.

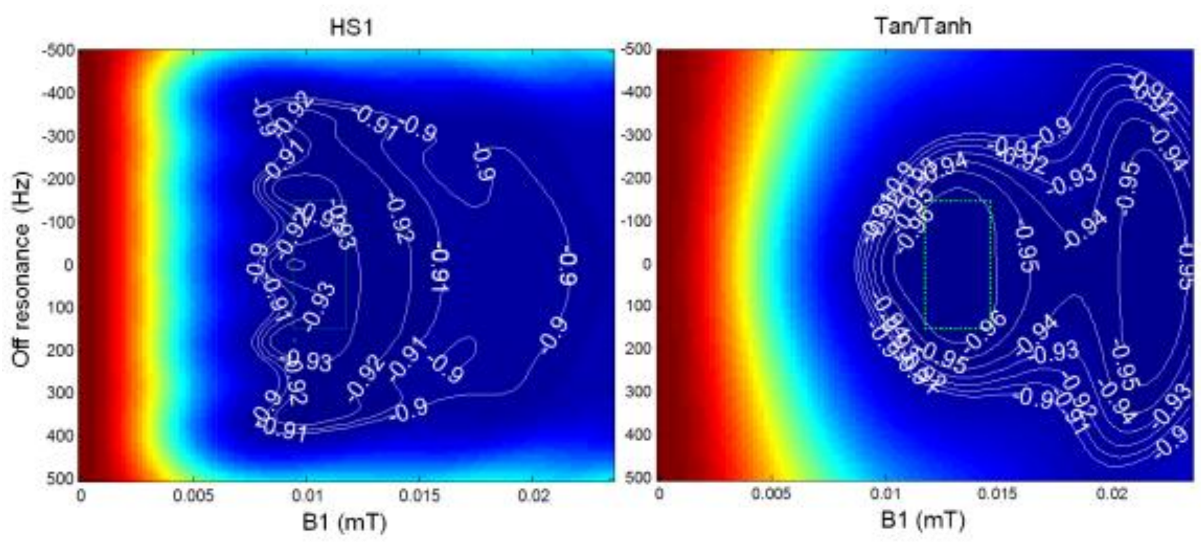

Figure 4. Response of adiabatic inversion pulse for T1=1000ms, T2=45ms using HS1 design "B" (left) and tan/tanh (right) design "A". Design region is indicated by dotted green box (25% amplitude range, ±150 Hz).

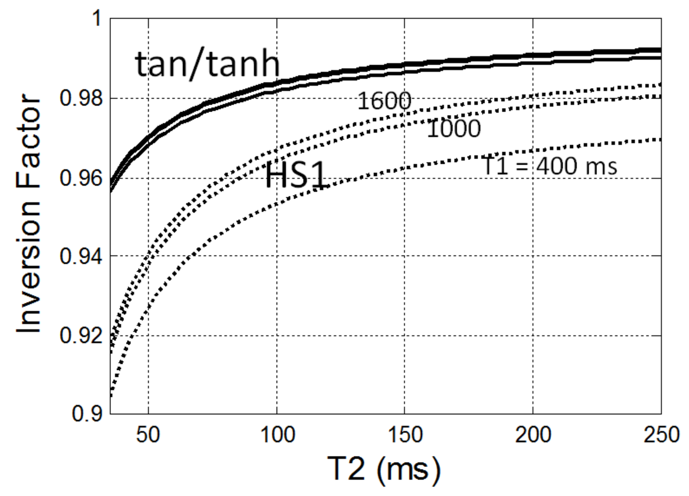

Figure 5. Dependence of adiabatic inversion factor on T2 for 10.24 ms HS1 design "B" (dashed) and 2.56 ms tan/tanh design "A" (solid) designs for T1 = 400, 1000, & 1600 ms. Note that design "A" has both higher inversion factor as well as reduced sensitivity to T1 and T2.

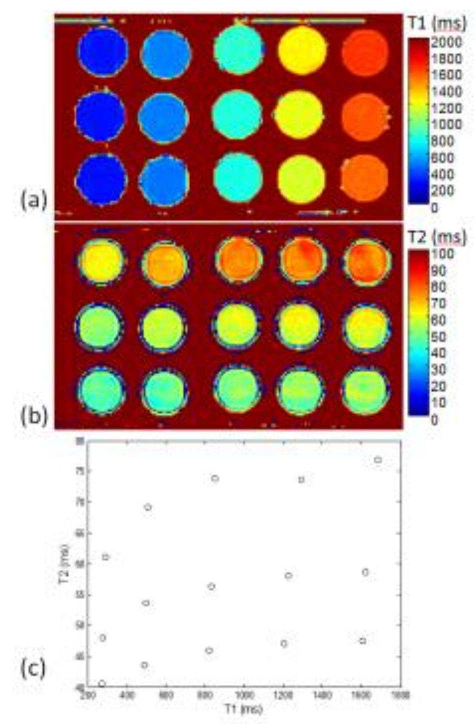

Figure 6. Measurements of phantom T1 and T2: (a) T1-map, (b) T2-map, and (c) T1 and T2 values for each phantom tube.

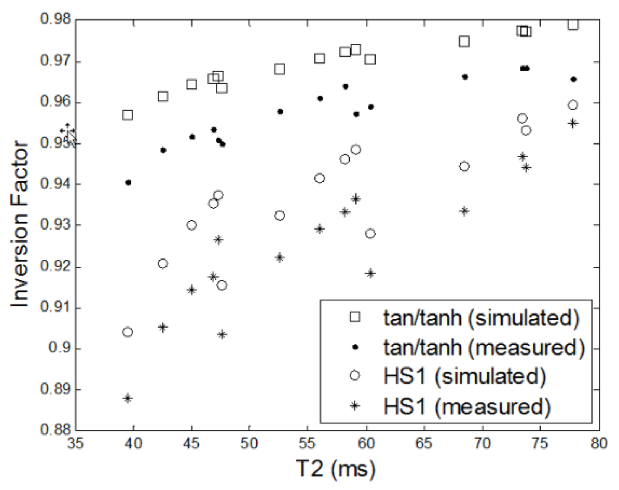

Figure 7. Measured and simulated inversion factor vs T2 (various T1) for phantom data using tan/tanh design "A" and HS1 design "B". Simulated values are calculated based on measured phantom T1 and T2 (Fig. 6(c)).

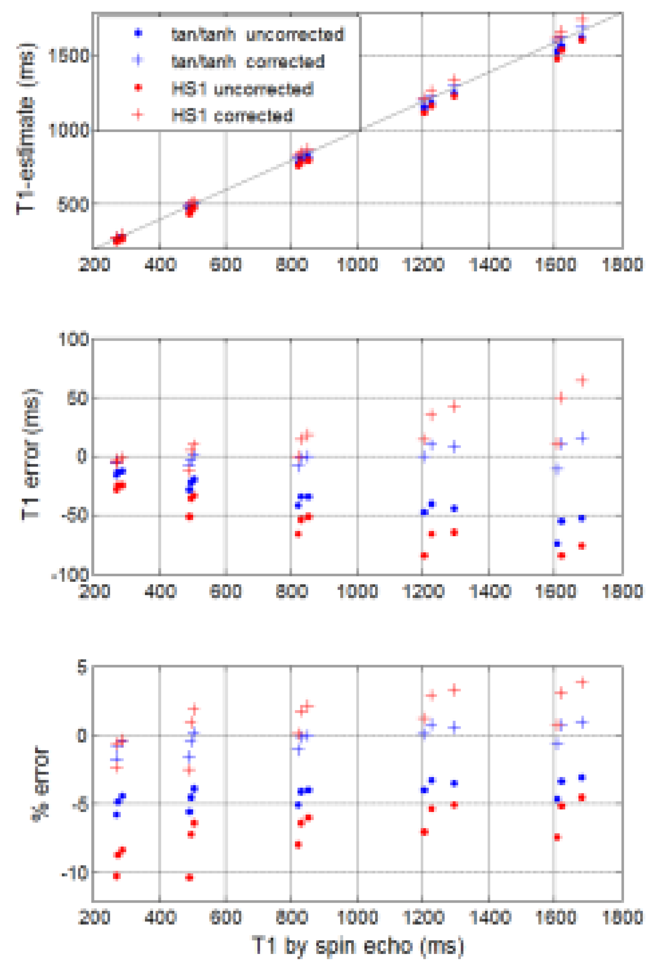

Figure 8. Estimated T1 after "Look-Locker" correction vs true T1 measured by spin echo with and without empirical correction for imperfect inversion for both the HS1 design "B" and tan/tanh design "A".

DISCUSSION

Non-ideal inversion leads to significant errors in inversion recovery based T1-mapping. The inversion efficiency of adiabatic pulses is sensitive to transverse relaxation. The tan/tanh design achieved the best performance subject to the peak amplitude constraint.

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.