A Robust and Low-Power Adiabatic T_2 Preparation for Cardiovascular Imaging at High Magnetic Field

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BACKGROUND – Cardiac magnetic resonance imaging (CMR) has been shown to benefit from the higher signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) available at higher magnetic field strength. However, in practice, CMR remains limited by the need for higher radiofrequency (RF) pulse power, since it is in turn limited by the maximum specific absorption rate (SAR). For example, at 3T, an adiabatic T_2 preparation module (T_2Prep, Figure 1A) [1], which is robust to RF inhomogeneity ΔB_1, can usually not be combined with high-SNR techniques such as balanced steady-state free precession (bSSFP) unless low nutation angles are applied. To decrease the SAR requirements of the T_2Prep and to allow it to be combined with bSSFP, we numerically optimized two hyperbolic secant (HSn) [2] adiabatic RF pulses and tested their performance for low-power T_2Prep refocusing in CMR at 3T.

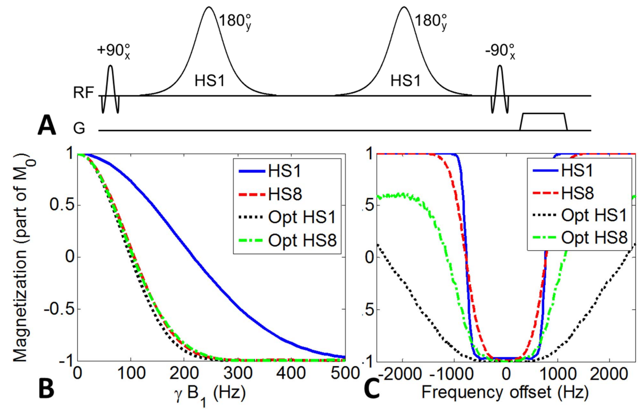

Figure 1. Adiabatic T_2 preparation and numerically optimized inversion. A) *Overview of a T_2 preparation module with two adiabatic HS1 refocusing pulses.* ***B)*** *On-resonance inversion power γB_1 requirements of the standard and TR-FOCI HSn pulses. The optimized HS1 pulse requires power similar to the standard HS8 pulse.* ***C)*** *Robustness of the same pulses to B_0 variability at pulse power γB_1=500Hz. While the poor original profile of the HS8 pulse is improved after optimization, it is especially the optimized HS1 that improves robustness.*

METHODS – A genetic algorithm based on Bloch equation simulations[3] was used to numerically optimize standard adiabatic HS1 (higher power requirement and ΔB_1 robustness) and HS8 pulses (lower power requirement and ΔB_1 robustness) to generate Time-Resampled Frequency-Offset-Corrected Inversion (TR-FOCI) pulses with a duration of 12ms and an inversion band of 300mm, which should easily cover the cardiac anatomy. The minimum energy requirements for satisfactory T_2Prep performance were assessed in agar-$NiCl_2$ phantoms and 8 healthy volunteers with a 2D radial bSSFP imaging sequence (nutation angle 70°, matrix 256^2, slice thickness 8mm, lines per heartbeat 35) on a 3T clinical MR scanner (Magnetom Skyra, Siemens, Erlangen, Germany) while monitoring SAR levels on the console of the system. The myocardium-to-blood CNR was calculated in both phantoms and volunteers, and the minimum required RF pulse energy for constant muscle-blood CNR and absence of visible artifacts was compared. The low-power T_2Prep was then combined with a navigator-gated and fat-suppressed 3D bSSFP pulse sequence (T_2Prep duration 40ms, nutation angle 90°, 28 lines per heartbeat) to assess the feasibility of T_2-prepared coronary angiography at 3T.

RESULTS AND DISCUSSION – The optimized pulses demonstrated superior performance in the simulations compared to standard HSn pulses (Figure 1). In the phantoms and volunteers, the TR-FOCI pulses required 54% less power than the HS1 pulse to achieve artifact-free images and a stable CNR (Figure 2), while images obtained with a standard HS8 pulse were never artifact-free. In vivo, the optimized pulses needed roughly half the energy of the standard HS1 pulse (Figure 2C), and the entire pulse sequence resulted in ~20% less overall SAR deposition in the volunteers for artifact-free images with similar CNR as the original images. The T_2-prepared coronary imaging enabled for the visualization of the coronary arteries in all volunteers (Figure 2F).

CONCLUSION – We successfully implemented numerically optimized adiabatic pulses and demonstrated that they require significantly less power for similar performance as standard HSn pulses in a T_2Prep, which critically enables the use of CMR with bSSFP and T_2Prep at 3T.

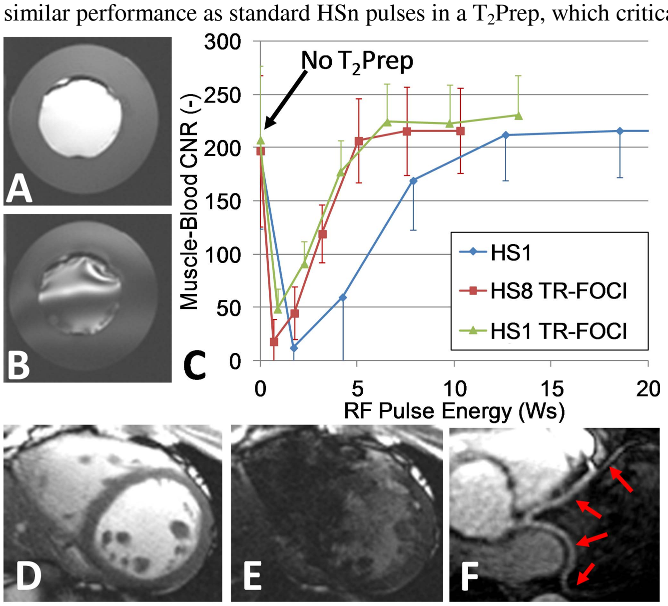

Figure 2. Application of the optimized adiabatic pulses in the phantoms and volunteers. A) *Radial bSSFP image of the phantom with compartment T_1 and T_2 values that approach blood (bright center) and myocardium (darker outer layer). A HS8-derived TR-FOCI pulse with pulse energy 4Ws was used in the T_2Prep.* ***B)*** *The same pulse sequence, but with a 4Ws standard HS1 pulse. Distortions due to insufficient pulse energy can be observed in both compartments.* ***C)*** *Contrast-to-noise ratio plots in the volunteers show that significantly less energy is required by the optimized pulses to obtain the same CNR as the standard HS1 pulse.* ***D)*** *and* ***E)*** *In vivo human T_2-prepared image with HS1-derived TR-FOCI pulses with energy ~4Ws: the superior performance of the optimized pulse compared to the standard HS1 pulse T_2Prep can be clearly observed.* ***F)*** *A reformat of the left coronary artery system (arrows) demonstrates the feasibility of an adiabatic T_2Prep together with high-nutation angle bSSFP.*

REFERENCES – [1] Nezafat et al., Magn Reson Med 2006, 55(4):858. **[2]** Silver et al. J Magn Reson 1984, 59(2):347. **[3]** Hurley et al., Magn Reson Med 2010, 63(1):51