Numerically optimized radiofrequency pulses for robust and low-power cardiovascular $T_2$ preparation at 3T

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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 strengths; however, in practice, CMR remains limited by the need for higher radiofrequency (RF) pulse power, which is in turn limited by the maximum specific absorption rate (SAR). For example at

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**Figure 1 Performance of the tailored pulses**

a) Example characteristics of the HS1-derived TR-FOCI pulse. Note that the optimized pulse is broad compared to the standard HS1 (dotted line).
b) Slice-excitation profile of the same HS1-derived TR-FOCI pulse. Above a low pulse power of $\gamma B_1 \approx 200$ Hz, the profile has a very sharp transition.
c) On-resonance inversion power requirements of the standard and TR-FOCI pulses. Once the HS1 pulse is optimized as a TR-FOCI pulse, it requires power similar to the standard HS8 pulse.
d) Robustness of the same pulses to B0 variability at pulse power $\gamma B_1 = 500$ Hz. While the poor original profile of the HS8 pulse is improved after optimization, it is especially the optimized HS1 that has improved robustness.

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3T, an adiabatic (robust to RF inhomogeneity $\Delta B_1$) $T_2$ preparation ($T_2$Prep, Nezafat et al., MagnResonMed2006) can usually only be combined with balanced steady-state free precession (bSSFP) acquisitions with low nutation angles, or is played out only once every several heartbeats. Thus the design of $T_2$Prep adiabatic inversion pulses requires a compromise between pulse performance and the energy deposition. To overcome this SAR limitation on $T_2$Prep, we therefore numerically optimized two hyperbolic secant (HSn; Silver et al. JMagnReson1984) RF pulses and tested their performance for $T_2$Prep refocusing in CMR at 3T.

**Methods**

A genetic algorithm based on Bloch equation simulations (Hurley et al., MagnResonMed2010) was used to numerically optimize standard adiabatic HSn (higher power requirement and $\Delta B_1$ robustness) and HS8 pulses (lower power requirement and $\Delta B_1$ robustness) to generate Time-Resampled Frequency-Offset-Corrected Inversion (TR-FOCI) pulses with a duration of 12 ms and an inversion band of 300 mm, which should easily cover the cardiac anatomy. The minimum energy requirements for satisfactory $T_2$Prep performance were assessed in agar-NiCl2 phantoms and 3 healthy volunteers with a 2D radial bSSFP imaging sequence (nutation angle 70°, matrix 256$^2$, slice thickness 8 mm, lines per heartbeat 35) on a 3T clinical MR scanner (Skyra, Siemens) while monitoring SAR levels. The myocardium-to-blood CNR was calculated in both phantoms and volunteers and the minimum required pulse energy for constant CNR and absence of artifacts was compared.

**Results**

The optimized pulses demonstrated superior performance in the simulations compared to standard HSn pulses.
pulses (Figure 1). The TR-FOCI pulses required 54% less power than the HS1 pulse to achieve artifact-free images and stable CNR (Figure 2), while images obtained with an HS8 pulse were never artifact-free. The optimized pulses needed roughly half the energy of the standard pulses, 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.

**Conclusions**

We successfully implemented numerically optimized adiabatic pulses and demonstrated that they required less power for similar performance to HSn pulses in a T2Prep, which critically enables the use of CMR with bSSFP and T2Prep at 3T.

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