Improved Fat Signal Suppression for Coronary MRA at 3T using a Water-Selective Adiabatic T_2-Prep Technique

Andrew J. Coristine[1,2], Ruud B. van Heeswijk[1,2], and Matthias Stuber[1,2]
[1]*CIBM-CVMR, Centre Hospitalier Universitaire Vaudois, Lausanne, VD, Switzerland,* [2]*FBM, Université de Lausanne, Lausanne, VD, Switzerland*

Introduction: At high field, B_0 and B_1 inhomogeneities may complicate fat saturation strategies[1], such as CHEmically Selective Saturation (CHESS) pulses[2], which are dependant on precise excitation angles and precessional frequencies. These fat saturation pulses, which are necessary for unambiguous visualization of cardiac anatomy, are often used in conjunction with magnetization preparation modules, such as T_2 Preparation (or T_2-Prep)[3], to improve blood/myocardium contrast. By modifying an adiabatic T_2-Prep[4] to be water-selective, off-resonance frequencies can be suppressed - adding an intrinsic fat signal attenuation that is less sensitive to B_0 and B_1 inhomogeneities - while preserving the T2-Prep's added contrast. Numerical simulations, phantom validation, and initial *in vivo* results are presented.

Methods: The first radiofrequency (RF) pulse of a +90°,180°,180°,-90° adiabatic T_2-Prep was reduced in bandwidth (BW), from 1250 Hz to 285 Hz, so as to only excite a range of frequencies. The BW of the final RF pulse (-90°) remains large (1250 Hz), encompassing both water and fat frequencies. As a result, magnetization of on-resonant spins is restored, whereas that of off-resonant spins, including fat, is tipped into the transverse plane and spoiled. The RF excitation angles of the first and last pulse were also increased to ±120°, to further reduce fat signal via inversion recovery. This water selective adiabatic T_2-Prep (WS-T_2-Prep) may then be used alone, or in combination with a typical fat saturation strategy such as a CHESS pulse.

To predict the effect of field inhomogeneities on such a combined approach, the excitation profiles of the WS-T_2-Prep + CHESS pulse (A) were simulated in MATLAB for a range of B_0 and B_1 values. These profiles were then compared to those of a *conventional* adiabatic T_2-Prep (C-T_2-Prep) + CHESS pulse (B). To validate these predictions, a homebuilt phantom, with compartments doped to mimic blood, myocardium, and fat, was scanned using strategies (A) and (B). All images were acquired on a 3T clinical scanner (MAGNETOM Trio, Siemens AG, Healthcare Sector, Erlangen, Germany) using a Cartesian ECG-triggered 2D segmented k-space gradient echo sequence, with FoV 192x192 mm^2, matrix size 192x192, 3.0 mm slice thickness, 15 k-space lines per (simulated) heartbeat, $TE_{T2\text{-}Prep}$ = 40 ms, FA 15°, TE/TR/Tacq=2.37/5.37/80.55 ms. The RF excitation angle of the CHESS pulse was varied from 1-360° and fat signal intensity was measured. As an "incorrect" flip angle may be regarded as a "known" B_1 inhomogeneity, a fat-suppression strategy robust against such inhomogeneity should be effective across a range of RF excitation angles.

For *in vivo* experiments, volume targeted, ECG-triggered and navigator-gated 3D images of the right coronary artery were acquired in 9 healthy adults. Both WS-T_2-Prep and C-T_2-Prep were used, with and without an additional CHESS pulse. Imaging parameters for all 4 sequences were as shown above, except for: FoV 360x258 mm^2, matrix size 240x216, 1.5 mm slice thickness, 20 k_z partitions. After acquisition, images were reformatted and analyzed using Soap-Bubble[5]. Fat suppression efficacy was compared using vessel sharpness and signal-to-noise (SNR) measurements in selected regions (abdominal fat, epicardial fat, blood, & myocardium). Statistical significance was determined using a paired 2-tailed Student's t-test.

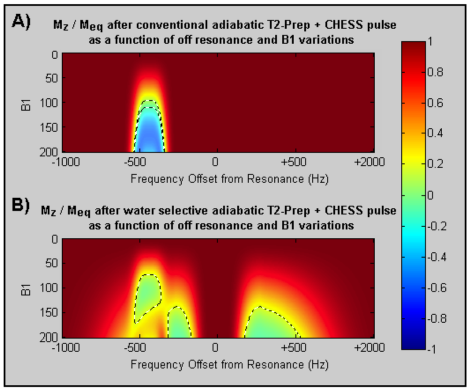

Figure 1: Numerical Simulations

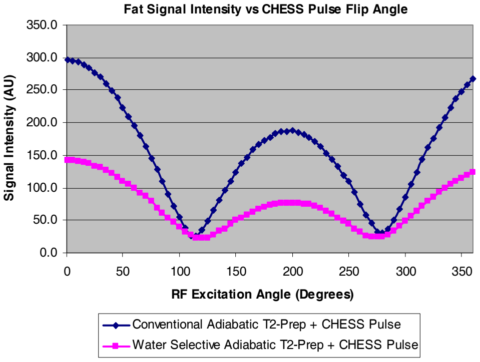

Figure 2: Phantom Experiments

Table 1: Mean SNR and Vessel Sharpness (± SD) in Tissue ROIs for Select Fat Saturation Strategies.

	No Additional Fat Saturation		**+ CHESS Fat Saturation Pulse**	
Region of Interest	Conventional Adiabatic T_2-Prep	Water Selective Adiabatic T_2-Prep	Conventional Adiabatic T_2-Prep	Water Selective Adiabatic T_2-Prep
Abdominal Fat	312.6 ± 116.2	192.3 ± 73.0 *	162.3 ± 72.8	79.4 ± 30.8 *
Epicardial Fat	103.9 ± 49.6	83.1 ± 50.9 *	28.0 ± 9.1	22.2 ± 4.6 *
Blood	59.8 ± 16.2	71.9 ± 14.4	69.8 ± 18.5	91.5 ± 19.9
Myocardium	36.9 ± 12.7	42.3 ± 20.5	35.3 ± 10.1	53.5 ± 11.9
Vessel Sharp	46.1 % ± 8.0 %	49.4 % ± 8.3 % *	66.5 % ± 6.1 %	72.2 % ± 5.5 % *

* Indicates a statistically significant difference between C-T_2-Prep and WS-T_2-Prep ($p<0.05$).

Results & Discussion: **Fig 1** shows the result of the numerical simulation. The color scale represents the longitudinal magnetization, M_z, immediately prior to imaging, as a fraction of the available magnetization, M_{eq}. The M_z/M_{eq} of both C-T_2-Prep+CHESS (top) and WS-T_2-Prep+CHESS (bottom) are shown as functions of B_1 and precessional frequency, with the dashed region representing an M_z/M_{eq} of 10% or less.

The combination of WS-T_2-Prep+CHESS increases both the range of frequencies (thus improving robustness to B_0 inhomogeneities) and the range of B_1 values (thus improving robustness to B_1 inhomogeneities) at which signal is suppressed. **Fig 2** shows the signal intensity of fat measured in phantom experiments, for various CHESS RF excitation angles. The WS-T_2-Prep+CHESS combination suppresses fat signal (magenta curve) more effectively at non-ideal B_1 values (represented by the variation in RF excitation angle) than does the C-T_2-Prep+CHESS combination (blue curve).

Sample images from the volunteer study are shown in **Fig 3**, with corresponding SNR measurements in **Table 1**. When no complementary fat saturation was used, the WS-T_2-Prep reduced abdominal and epicardial fat signals by 38% and 20%, reduced background noise by 21% and improved vessel sharpness from 46.1% to 49.4%, as compared to the C-T_2-Prep alone (all $p<0.05$). When a CHESS pulse was added prior to imaging, the WS-T_2-Prep reduced abdominal and epicardial fat signals by 61% and 37%, reduced background noise by 13%, and increased vessel sharpness from 66.5% to 72.2%, as compared to C-T_2-Prep + CHESS (all $p<0.05$). Blood and myocardium SNRs were not significantly affected.

Conclusions: A water-selective adiabatic T_2 Preparation pulse significantly improves fat saturation in 3T coronary MRA and should be considered as a potential addition to conventional fat saturation strategies.

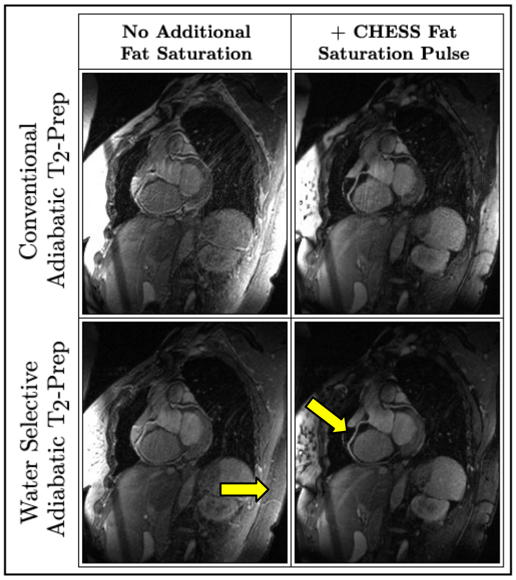

Figure 3: In Vivo Comparisons

1. Nezafat, MRM 61:1326 (2009) **2.** Haase, PMB 30:341 (1985) **3.** Britain, MRM 33:689 (1995) **4.** Nezafat, MRM 55:858 (2006) **5.** Etienne, MRM 48:658 (2002)