Phase Sensitive Fat Darkening by TI-Minimized Double SPAIR (PHATTI DeSPAIR) for Robust and Highly Effective Fat Suppression in Clinical T1-Weighted Imaging of Ischemic and Non-Ischemic Heart Disease

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Background: Protocols that impart T1-weighting by an inversion recovery (IR) pulse, such as delayed enhancement, can incorporate a standard fat saturation, but this fat suppression performs poorly with clinically useful readout lengths and linear reordering. Centric reordering improves fat suppression, but causes undesirable image blurring. Applied to the phase-sensitive inversion recovery (PSIR) sequence, fat saturation works even worse due to its rescaling of image brightness based on the most negative species in the image. For clinical imaging, complete fat suppression is highly desirable when imaging ischemic and non-ischemic heart disease to discriminate fat from scar, which both appear bright on T1-weighted contrast-enhanced images. It would allow for improved visualization of scar without confounding fat signal, and for the assessment of fatty infiltrations in arrhythmogenic right ventricular dysplasia (ARVD). In the absence of an IR pulse, fat can be efficiently suppressed by a Spectral Selection Attenuated Inversion Recovery (SPAIR) pulse, but in its presence this approach cannot be readily applied. Fat would experience the IR pulse and would not be fully recovered when the SPAIR pulse is applied, resulting in such a short effective inversion time that fat nulling would be impossible. To address this problem, we previously developed the double-SPAIR (DeSPAIR) [1] method. We now present a further improvement to this technique achieved by combining it with a minimization of the fat inversion time and a phase-sensitive readout, with the added benefit of compatibility with PSIR. Fat signal becomes negative and appears completely black in phase-sensitive images. We call this method **ph**ase sensitive f**at** darkening by **TI**-minimized double SPAIR, PHATTI DeSPAIR.

Methods: The PHATTI DeSPAIR sequence is shown in figure 1. SPAIR 1 immediately follows the non-selective IR (NSIR) pulse to re-invert fat magnetization and return it to +M0. SPAIR 2 is played right before the readout (RO) resulting in negative fat magnetization at the k-space center for clinically relevant readout lengths (80 - 160ms). Normal myocardium is nulled at the k-space center by the NSIR pulse placed TI prior to the center. Black fat, dark grey myocardium, and bright scar result in the phase-sensitive image. In 13 patients (8 at 1.5T, 5 at 3T, Siemens MAGNETOM Avanto and Verio, 4 ischemic, 9 non-ischemic) we ran 3 scans per patient using no fat suppression (NONE), standard fat saturation (FS), and PHATTI DeSPAIR, and reconstructed 3 phase-sensitive and 3 magnitude images. In each phase-sensitive image, we measured the mean signal (MS) in multiple red dashed fat regions of interest (ROI), see figure 2. We measured MS rather than signal-to-noise ratio (SNR), because the calculation of SNR in phase-sensitive images is problematic. To quantify suppression efficiency, MS of FS and PHATTI DeSPAIR were divided by MS of NONE in the same ROI and expressed in percent. In the magnitude images, cavity (green ROI) and normal myocardium (yellow ROI) SNR were measured to evaluate if FS or PHATTI DeSPAIR would affect SNR. An ANOVA with Bonferroni correction was applied to test for statistical differences between the groups NONE, FS, and DeSPAIR.

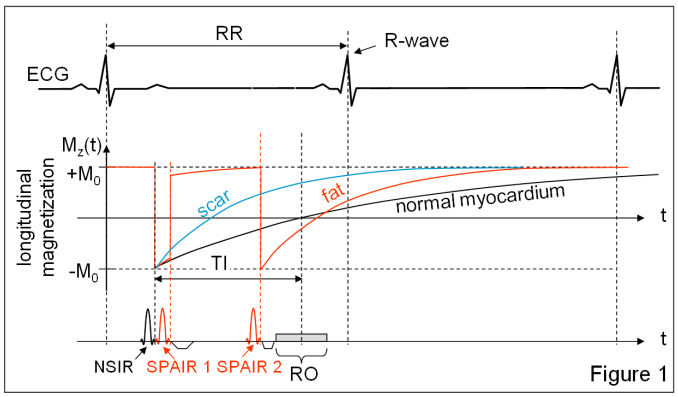

Figure 1

Results: Figure 2 shows typical phase-sensitive delayed enhancement images in a patient with pericardial fat using NONE, FS, and PHATTI DeSPAIR at 1.5T. Visual inspection shows the excellent suppression of pericardial and subcutaneous fat by PHATTI DeSPAIR, but hardly any by FS. Statistical analysis of MS revealed significantly suppressed fat by DeSPAIR at 1.5T and 3T ($p<0.001$ compared to NONE), see table 1. FS suppressed fat neither at 1.5T nor at 3T ($p>0.05$). Neither cavity nor myocardial SNR were statistically different ($p>0.05$) between any of the techniques, at both field strengths.

Conclusions: PHATTI DeSPAIR reliably renders fat signal black at both field strengths for clinically relevant readout lengths without compromising SNR, whereas FS has no effect on fat at either field strength. PHATTI DeSPAIR is compatible with PSIR and, due to the phase-sensitive nature of its reconstruction, can work for a range of slightly different fat T1 values. It requires no manual parameter adjustment — only a simple change to an existing sequence. In clinical practice, PHATTI DeSPAIR can facilitate the discrimination of fat and scar in ischemic and non-ischemic heart disease, and potentially improve patient outcome.

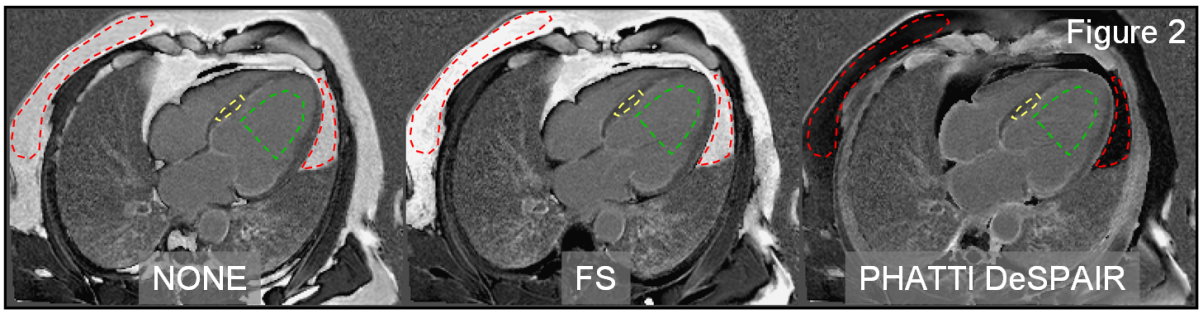

Figure 2

Table 1	1.5 T			3 T		
	NONE	FS	PHATTI DESPAIR	NONE	FS	PHATTI DESPAIR
fat [%]	100	97.6 ± 13.3*	59.5 ± 7.0#	100	99.4 ± 15.3*	73.9± 4.1#
SNR blood	19.0 ±10.0	19.7 ± 8.3*	17.3 ± 7.7*	28.1 ± 9.5	30.2 ± 11.0*	26.2 ± 13.0*
SNR myocardium	4.1 ± 2.4	3.8 ± 1.6*	3.6 ± 1.7*	6.4 ± 1.9	6.7 ± 3.6*	7.4 ± 4.5*

mean ± standard deviation; #: different to NONE, $p < 0.001$; *: identical to NONE, $p > 0.05$

References:

[1] Rehwald et al: "Simultaneous Nulling of Fat and Viable Myocardium in Delayed Enhancement Imaging - A New Approach to Fat Suppression at 1.5 and 3 Tesla Employing Multiple SPAIR Pulses", Proc. Intl. Soc. Mag. Reson. Med.19 (2011), 2622.