Black-blood T1 mapping at 3T: Reduced partial-voluming using adiabatic MSDE preparation

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Background
Myocardial T1 mapping in pathologies with decreased myocardial wall thickness such as dilated cardiomyopathy (DCM) is strongly impaired by partial-voluming from the neighboring blood pools [Kellman et al., JCMR2014]. Significant differences between the T1 times in myocardium and blood lead to decreased accuracy in the presence of partial-voluming. This causes sensitivity to the region-of-interest (ROI), compromising the inter-observer reproducibility.

The aim of this work is to study the use of blood-signal suppression using a motion-sensitized driven equilibrium (MSDE) [Wang et al., MRM2007] magnetization preparation in order to reduce partial-voluming in myocardial T1 mapping.

Methods
An adiabatic MSDE preparation module was added directly before the imaging pulses of a SAPPHIRE sequence [Weingärtner et al., MRM2014] (Fig. 1). The preparation consists of a rectangular tip-down pulse, an adiabatic B1ref1 refocusing pulse, a composite tip-up pulse and motion-sensitizing gradients before and after refocusing. The MSDE parameters were TEMSDE = 11 ms, gradients: amplitude = 16 mT/m, duration = 2 ms.

6 healthy volunteers (25 ± 6 y; 4 M) were scanned using conventional and black-blood T1 mapping on a 3T MR Scanner (Siemens Skyra). T1 mapping was performed using a bSSFP imaging readout with the following parameters: TE/TR/α = 1.0 ms/2.9 ms/35°, FOV/res = 440 × 375 mm²@1.7 × 1.7 mm², sl.th. = 8 mm, GRAPPA = 2, Partial-Fourier = 6/8, bw = 1085 Hz/px.

A three parameter model was used for T1 fitting, avoiding potential quantification inaccuracies caused by the recovery curve modulation through the MSDE preparation. T1 times, the average thickness and the apparent in-plane area of the myocardium were quantified in the T1 maps using manually drawn ROIs. Furthermore, cross myocardial T1 times were analyzed from the endo- to the epicardial border.

Results
Visually strong blood suppression was achieved using the adiabatic MSDE preparation (Fig. 2a). Quantitative analysis reveals increased T1 times towards the myocardial borders in conventional T1 mapping (Figure 2c), while consistent T1 times through the entire myocardial thickness were measured using black-blood SAPPHIRE. No significant difference was found in the average T1 time of the two methods (Conv.: 1574 ± 52 ms vs BB: 1593 ± 47 ms). A 25%-28% gain in apparent in-slice area of the myocardium and average wall-thickness in the T1 maps was achieved using blood-suppression (BB: 1596 ± 266 mm², 7.37 ± 1.16 mm vs. Conv.: 1278 ± 213 mm², 5.72 ± 0.87 mm, p < 0.05).

Conclusions
An adiabatic MSDE preparation enables robust myocardial T1 Mapping at 3T. The apparent myocardial in-slice area and average wall-thickness is significantly increased using a black-blood preparation. Furthermore, elevated T1 times at the myocardial borders were eliminated. This reduces sensitivity to ROI placement and potentially benefits the reproducibility of myocardial T1 mapping, especially in the presence of pathologies with reduced myocardial wall-thickness.
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**Figure 1** a) Sequence diagram of the SAPPHIRE black-blood $T_1$ mapping sequence. An adiabatic MSDE preparation is inserted directly before the imaging pulses. In MSDE, blood-signal suppression is caused by symmetric dephasing gradients before and after a refocusing pulse, causing incomplete refocusing of moving tissue and greatly increasing the blood/myocardium contrast. b) Simulated magnetization signal at the various inversion times of a SAPPHIRE sequence. High signal is observed in conventional $T_1$ mapping from the blood pools despite the long $T_1$ time. Black-blood SAPPHIRE shows almost complete suppression of the blood signal for the trade-off against a slightly decreased dynamic range in the myocardial signal.

**Figure 2** a) $T_1$-weighted images of a healthy volunteer with and without MSDE magnetization preparation. Visually strong and homogenous suppression of the blood-signal can be observed. b) Corresponding $T_1$ quantification in the myocardium using conventional and black-blood $T_1$ mapping. Visually homogenous $T_1$ times are observed around the myocardium using both methods. c) $T_1$ times through the myocardial thickness analyzed separately for the anterolateral, inferolateral and septal part of the myocardium. Conventional $T_1$ mapping shows strongly elevated $T_1$ times at the endo- and/or the epicardial border. No such elevation is observed with black-blood $T_1$ mapping.