3D black-blood T1 mapping of the mouse heart using IntraGate FLASH and DESPOT1 analysis

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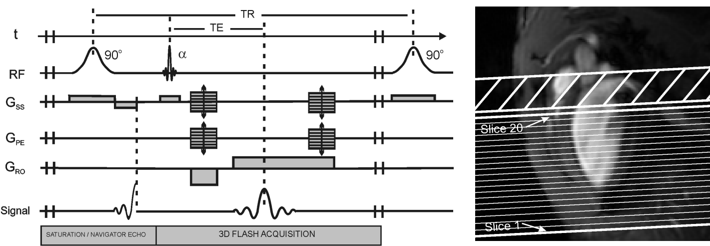
Introduction The mouse serves as a good model for studies on cardiovascular diseases, such as myocardial infarction. Cardiac function can for instance be assessed using high time resolution CINE imaging. Additionally, DCE imaging is able to differentiate between viable and infarcted myocardium. Recently, molecular imaging techniques are being developed, allowing contrast agents to specifically target disease markers, providing additional information about the infarction [1, 2]. Quantification of these contrast agents could be achieved by obtaining T_1 maps of the myocardium. To our knowledge, only one method has been used to quantify T_1 in the mouse heart, based on an ECG-gated IR FLASH sequence. However, usually only a single 1-1.5 mm slice is imaged with relatively long acquisition times ranging from 10 to 45 min. [3, 4]. This mainly depends on the number of averages and number of k-lines acquired during each inversion time. **Aim:** The goal of this study was to develop a fast and robust technique for 3D quantification of T_1 in the mouse heart. Our method uses a combination of 3D IntraGate FLASH steady-state imaging together with DESPOT1 analysis. The 3D IntraGate FLASH makes use of a navigator echo that retrospectively triggers the acquisition to the heart beat and respiration cycle [5]. The acquisition is not interrupted, thereby maintaining a constant TR needed for the DESPOT1 analysis [6]. Instead of taking the navigator echo from within the imaging volume, a separate slice on top of the heart was used to create the navigator echo (Fig. 1). All reconstructed slices from the 3D volume are therefore in the same cardiac phase. By using a 90° pulse for the navigator slice, the inflowing blood is saturated to improve contrast between the myocardium and heart lumen while at the same time reducing inflow artifacts.



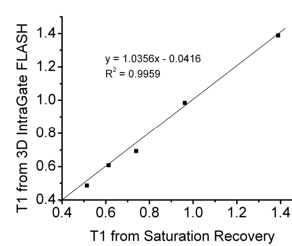


Figure 1: 3D black-blood IntraGate FLASH sequence. A saturation slice on top of the heart creates a navigator echo that retrospectively triggers the subsequent 3D FLASH acquisition of the left ventricle. A representative geometry is shown.

Figure 2: Comparison of T_1 values (s) calculated from Saturation Recovery data and 3D IntraGate FLASH data.

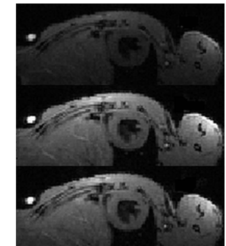


Figure 3: *In vivo* images at three different flip angles (top: 2°, middle: 8°, bottom: 14°).

Materials and Methods C57Bl/6 mice were scanned in a 9.4T experimental scanner (Bruker BioSpin, Ettlingen). Mice were placed in prone position on a 4-element phased array surface receive coil. Both were placed in a 72 mm volume transmit coil with the mouse heart exactly in the coil centre. A reference sample was placed underneath the mouse. The acquisition parameters were as follows: 2 ms slab selective RF pulse, FOV = 30×30×10 mm^3, AcqMatrix = 128×128×20 pixels, TR/TE = 10/2.5 ms, NA = 8. Blood saturation was performed every TR using a 1.5 ms Gauss pulse (ST = 3 mm). Retrospective reconstruction resulted in 6 different cardiac frames. To allow for T1-mapping, RF-spoiling was used and images were acquired at 5 different flip angles (α = 2°,5°,8°,11°,14°). The imaging time was 5 min. for each flip angle. DESPOT1 analysis was performed for each pixel separately as reported earlier by Deoni et al. The resulting T_1 and M_0 values were inserted into the Ernst equation and R^2 values were determined with respect to the data points to test the quality of the fitting. In each slice, the mean T_1 in the myocardium was calculated by drawing an ROI in the T_1 maps. For comparison, a bright blood version of the method was performed by changing the flip angle in the navigator slice to 2°, preventing saturation of the blood. To check the performance of the method, phantom experiments were done with equal imaging parameters on solutions (10 mg/l $MnCl_2$) with various concentrations of Gd-DOTA.

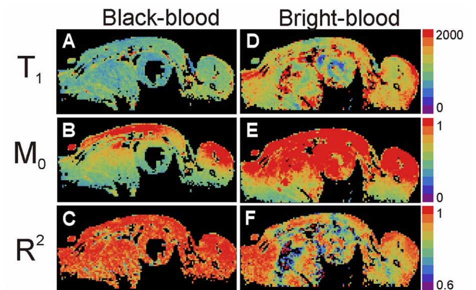


Figure 4: Cropped images of myocardial T1 maps (A,E), M0 maps (B,E) and R^2 maps (C,F) from DESPOT1 analysis. Experiments were done with blood suppression (A,B,C) and without (D,E,F)

Results Phantom experiments show that T_1 determination using the 3D IntraGate FLASH method in combination with DESPOT1 analysis is in excellent agreement with Saturation Recovery experiments (Fig. 2). *In vivo* anatomical images at three different flip angles are shown in Fig. 3. These images are taken from the exact same frame in the data (slice 15, cardiac frame 4/6) indicating that retrospective triggering allows perfect synchronization of subsequent scans. Also notice the excellent blood suppression that was achieved. T_1, M_0 and R^2 maps are shown in Fig. 4. The black-blood method results in very homogeneous myocardial T_1 values with R^2 values close to 1. On the other hand, T_1 maps from the bright-blood method show large variations in T_1 and lower R^2 values. The gradual decrease in M_0 clearly represents differences in coil sensitivity throughout the FOV. Saturation of the blood results in an additional decrease of M_0. T_1 values in different slices of the heart are very constant (Fig. 5). From the reference phantom, it is clear that there are no variations in T_1 due to slab selection or B_1 inhomogeneities. Striking is the difference between myocardial T_1 values resulting from the black-blood method (≈ 800 ms) compared to the bright-blood method (≈ 1300 ms). Other tissues in the FOV are equally affected by the blood suppression (Fig. 4). With respect to changes of myocardial T_1 during the heart cycle (not shown), it was noticed that the bright-blood method resulted in a periodic variation of T_1 which peaks at end systole, while for the black-blood method no significant variations were observed. For the reference phantom, there were no differences between the black-blood and bright-blood method.

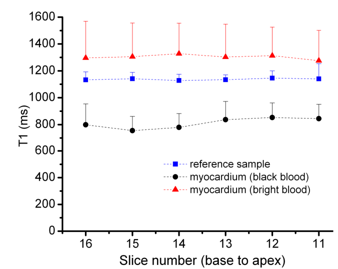


Figure 5: T_1 variation between slices. Values are mean ± SD

Discussion This study shows the possibility to obtain high quality 3D T_1 maps of the mouse heart. The choice for slab thickness and number of slices is a compromise between imaging time, resolution and SNR. Because our method is based on a steady-state imaging sequence, we were able to create T_1 maps of multiple 0.5 mm slices from base to apex in 25 min, covering 6 cardiac frames. This is impossible when using single slice approaches. The steady-state condition gives much freedom in improving spatial resolution or the number of cardiac frames, which is much harder using IR techniques. The 3D approach also does not suffer from through-slice motion between excitations. More important, this method will allow dynamic monitoring of T_1 after contrast injection with exactly the same imaging parameters and using only one additional scan for each time frame, providing a post-contrast T_1 map every 5 min. Using blood saturation serves as an crucial feature of the method, minimizing flow artifacts that were seen in bright-blood diastolic images and giving less variability in T_1. The effect of blood saturation on the mean value of T_1 was surprisingly high. Considering the continuous saturation of inflowing blood as well as that flowing out of the aorta, the direct contribution of blood to the steady-state signal or via exchange of magnetization with the tissue can be totally different. Because blood has a high T_1, lower T_1 values for the black-blood method should be expected.

References [1] Caravan, P. et al. Angewandte Chemie-IE 2007;46:8171-8173. [2] Nahrendorf, M et al. Circulation 2008;117:1153-1160. [3] Streif, JUG. et al. MRM 2005;53: 584-592. [4] Waghorn, B. NMR Biomed 2008. [5] Heijman, E et al. NMR Biomed 2007;20:439-447. [6] Deoni, SCL. et al. MRM 2003;49:515–526.