Saturation recovery single-shot acquisition (SASHA) for T_1 mapping in the human heart at 7T

Christopher T. Rodgers[1], Yuehui Tao[1], Stefan Piechnik[1], Alexander Liu[1], Jane Francis[1], Stefan Neubauer[1], and Matthew D. Robson[1]
[1]*University of Oxford, Oxford, Oxon, United Kingdom*

PURPOSE: Myocardial T_1 mapping at 1.5T and 3T distinguishes powerfully between normal and diseased tissue with focal and diffuse pathology.[1] We recently reported the first human myocardial T_1 values at 7T using the ShMOLLI+IE inversion recovery sequence.[2] Yet even using a unique 7T scanner with 16kW RF output, perfect magnetization inversion was impossible. We now introduce a saturation recovery method to enable myocardial T_1 mapping with standard commercial 7T MRI scanners.

METHODS: The saturation recovery single-shot acquisition (SASHA) sequence[3] was modified for 7T by using: an optimised train of 4xHS8 pulses to saturate[4] and 10 FLASH readouts with saturation delays (T_S): non-saturated, 100, 200, 300, 400, 500, 600, 650ms, 1hb + 100ms and 1hb + 700ms in a 12 heartbeat breath-hold. Data were acquired with a Siemens 7T MRI scanner (with 8kW RF), an 8-element cardiac coil and ECG gating. Signals were fitted pixelwise to "$s(T_S) = A - B \exp(-T_S / T_1)$".

10 healthy subjects (males, 22-45yrs, 70-84kg) were recruited according to local ethics regulations. For each subject, coil tuning, B_0- shims, B_1-shims and the central frequency were optimised over the left ventricle. Then 7T SASHA native (i.e. non-contrast) T_1 mapping was performed in short axis (SAX) and horizontal long-axis (HLA) views.

In three subjects, post-contrast T_1 maps were acquired ~5min after 2 peripheral bolus injections of Dotarem Gd contrast agent with a power injector (Accutron MR, MEDTRON).

RESULTS: "7T SASHA" T_1 values were validated against IR-SE reference T_1 values in a $NiCl_2$-doped agar and carrageenan phantom; values agreed to within 6% for readout flip angles ≤25° (Fig. 1).

In-vivo, the native 7T SASHA T_1 values in the interventricular septum were 1939±73ms. T_1 values in the ventricular blood pools showed strong artefacts, likely due to blood flow. The post-contrast T_1 values were 999, 1107 and 1674ms in myocardium and 472, 567 and 966ms in blood for Dotarem doses of 2x 50, 50 & 25 and 2x 13.5 µmol/kg in the three subjects respectively. Post-contrast T_1 maps were acquired too soon after bolus infusion to permit calculation of extra-cellular volumes.

These myocardial T_1 values agree with our ShMOLLI+IE finding of a myocardial T_1 = 1925 ± 48 ms. However, with ShMOLLI+IE we had to use a 4-parameter model-based fitting procedure to correct for imperfect inversion, read-out induced saturation and spin history effects. In contrast, with 7T SASHA, it is now possible to achieve comparable T_1 values using a simple 3-parameter fit (on the scanner). Note that these considerations at 7T are different to the well-known differences between MOLLI and SASHA T_1 values at 1.5 and 3T caused by imperfect inversion,[2] T_2 relaxation,[5] and magnetization transfer.[6]

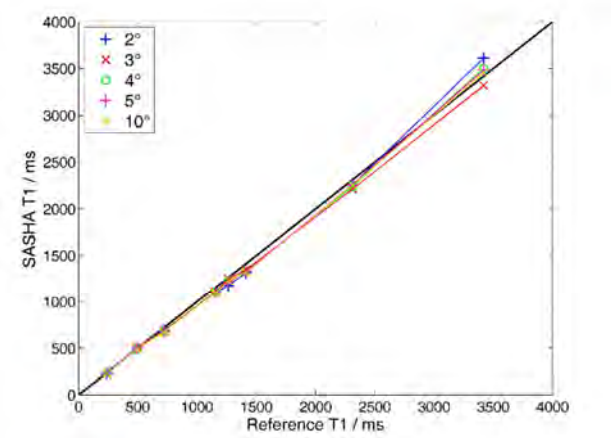

Figure 1: Phantom validation of 7T SASHA sequence T_1s against inversion-recovery-spin-echo (IR-SE) reference in tubes of $NiCl_2$-doped agar and carrageenan. Reference data were acquired in a 32-channel head coil (Nova Medical) to ensure sufficient B_1^+ for reliable inversion across the phantom. 7T SASHA data were acquired using the 8-element cardiac coil. For FLASH readout flip angles <20°, the 7T SASHA T_1s are within 6% of the IR-SE reference T_1s. Spin echo (SE) reference T_2s were 50-300ms in this phantom.

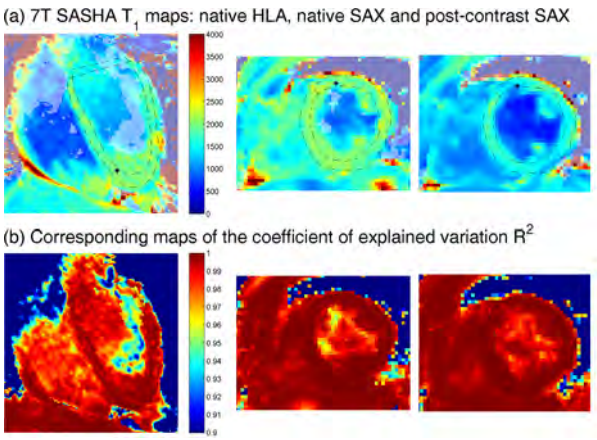

Figure 2: In-vivo results from a healthy volunteer. Top: Myocardial T_1 maps in a horizontal long axis view (left); mid-short-axis view (centre); and the same mid-short-axis view after administration of Dotarem Gd contrast. Bottom: Corresponding maps of the coefficient of variation R^2. Note how the centre of the LV blood pool has poor R^2 and anomalous T_1 values. We believe this is due to blood flowing to/from regions of lower B_1^+ than the heart.

CONCLUSIONS: Saturation recovery allows T_1 mapping in the human heart using a commercial 8x1kW 7T MRI scanner. T_1 values from 7T SASHA with 3-parameter fitting and ShMOLLI+IE with 4-parameter fitting are comparable in normal volunteers at 7T. Our findings hold promise for wider clinical applications of T_1 mapping at ultra-high fields.

1. Moon et al., JCMR, 2013. 2. Rodgers et al., MRM, 2013. 3. Chow et al., MRM, 2013. 4. Tao et al., MRM, 2014. 5. Chow et al., SCMR 2012. 6. Robson et al., MRM, 2013. Funded by the Wellcome Trust and Royal Society [098436/Z/12/Z]; MRC; and NIHR Oxford BRC.