Dynamic tracking of manganese uptake in mouse hearts by rapid multi-slice $T_1$ mapping

Kai Jiang, Xin Yu*

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Background
Manganese ($Mn^{2+}$)-enhanced MRI (MEMRI) has the potential for in vivo assessment of the voltage-gated $L$-type $Ca^{2+}$ channel activity. Quantitative assessment of $Mn^{2+}$ uptake via $Ca^{2+}$ channels requires fast and accurate $T_1$ mapping. In the current study, a multi-slice saturation recovery Look-Locker (MSRLL) method was developed for $T_1$ mapping of the whole mouse heart in < 3 min.

Methods
MSRLL Sequence
A schematic diagram of the MSRLL pulse sequence is shown in Figure 1. An ECG-triggered saturation module was applied at the beginning of each phase-encoding step, followed by the acquisition of k-space lines along the magnetization recovery curve in multiple slices. ECG-triggered image acquisition was performed at late diastole.

Phantom Study
All MRI studies were performed on a horizontal 7.0T Bruker scanner with a 35 mm volume coil. The MSRLL method was first validated in vitro using a multi-compartment phantom with $MnCl_2$ solution ranging from 30 $\mu$M to 1000 $\mu$M. $T_1$ maps of 5 slices were compared with those acquired with a previously validated single-slice method (SRLL). Imaging parameters were: flip

![Figure 1 MSRLL pulse sequence](image-url). After 90° non-slice selective saturation pulses, 10 sequential multi-slice FLASH acquisitions separated by an interval $\tau$ were applied. Each block on the relaxation curve represents a multi-slice acquisition module.
In Vivo Study
In vivo MEMRI studies were performed in 3-month-old FVB mice (n = 19). \( T_1 \) maps of three adjacent short-axis slices at mid-ventricular levels were acquired with the same imaging parameters as those used in vitro. Continuous \( T_1 \) mapping was performed during the 30 min of MnCl\(_2\) infusion through tail vein (0.2 mL/hr) and the 15 minutes washout. To investigate the Mn\(^{2+}\)-induced relaxivity changes, two different MnCl\(_2\) solutions at

**Figure 2 R\(_1\) changes in dynamic MEMRI study.** a-c. Pre-contrast \( T_1 \) maps of the three slices. d-f. Post-contrast \( T_1 \) maps of the three slices. g. Time courses of \( R_1 \) changes.
126 mM (n = 9) and 63 mM (n = 10) were used. Validation study was performed either at baseline (n = 10) or post-contrast (n = 10).

Results
In vitro studies showed strong agreement between MSRLL and SRLL. Average imaging time in vivo was 140–166 s. Shown in Figure 2 are representative T1 maps acquired at baseline (Figure 2a-c) and after Mn²⁺ infusion (Figure 2d-f). All three slices showed significant reduction in T1 after Mn²⁺ infusion. The time courses of the R1 changes for all three slices are presented in Figure 2g. In general, higher Mn²⁺ dose induced larger increase in R1 during Mn²⁺ infusion.

Conclusions
An ECG-triggered, multi-slice saturation-recovery Look-Locker method was developed for fast and complete cardiac T1 mapping in mice. Validity and utility of this method was well demonstrated in the phantom and in vivo two-dose MEMRI studies.

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