Fast and robust 3D T1 mapping using spiral gradient shape and continuous radio-frequency excitation at 7 T : Application on cardiac Manganese Enhanced MRI (MEMRI) in mice

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TARGET AUDIENCE : This study is aimed at scientists who need to perform fast in vivo 3D T_1 quantification on a small animal hearts .

BACKGROUND : Mapping the longitudinal relaxation time (T_1) is a promising quantitative tool for the detection of myocardial pathologies either in mouse or human. T_1 maps are usually obtained in 2D in order to reduce the total scan time. However, to diagnose myocardial infarction it might be useful to obtain the T_1 maps in three dimensions (3D) which require a long acquisition time. In this project a new 3D T_1 mapping method based on Look-Locker protocol using continuous radio frequency (RF) excitation and spiral gradient shape has been developed. This method allows to obtain 3D maps with high spatial (200 x 200 x 300 μm^3) and temporal resolution (<12 min). Moreover, manganese injections demonstrated the capacity of this method to detect T_1 changes in both healthy and ischemic mouse hearts.

METHODS : All the mice were imaged on a 7T horizontal magnet (Bruker Biospin) equipped with a gradient system capable of 660 mT/m maximum strength and 110 µs rise time. A volume resonator (75.4 mm inner diameter, active length.70 mm) operating in quadrature mode was used for excitation, and a four-element (2x2) phased array surface coil (outer dimensions of one coil element: 12 x 16mm^2; total outer dimensions: 26 x 21 mm^2) was used for signal reception.The acquisition sequence begins with an inversion pulse allowing to inverse the longitudinal magnetization. Then, a continuous RF pulse train synchronized with the mouse electrocardiogram was applied to acquire images at different inversion times. To reduce the acquisition time, two spiral interleaves were acquired per RR interval. For each experiment twenty-three 3D images spaced from a R-R interval (~140ms) were acquired during the signal relaxation. A new fitting protocol has also been developed which takes into account the lower magnetization equilibrium induced by the continuous RF excitation. The precision of this protocol was validated on a phantom with various concentrations of $MnCl_2$. T_1 were measured using a gold standard inversion-recovery (IR) and the new developed method. To test the robustness of this method in vivo on healthy and, on ischemic mice, T_1 maps were acquired after 6 successive injections of $MnCl_2$ at 50mM in 5 healthy mice corresponding to an increasing $MnCl_2$ dose from 25 $\mu mol.kg^{-1}$ to 150 $\mu mol.kg^{-1}$. For ischemic mice, the T_1 maps were acquired after injection of 60 µL of $MnCl_2$ at a concentration of 50 mM (injected dose : 150 µmol.kg-1). The following imaging parameters were used : matrix=96x96x48 ; field-of-view=20x20x15mm^3 ; TR/TE=6/1.5ms; bandwidth=300kHz; imaging pulse = Sinc with a 10° flip-angle; inversion pulse : Gauss 512 with 180° flip-angle; twenty-three 3D images / experiments; one 3D image / cardiac cycle; R-R interval ~140 ms.

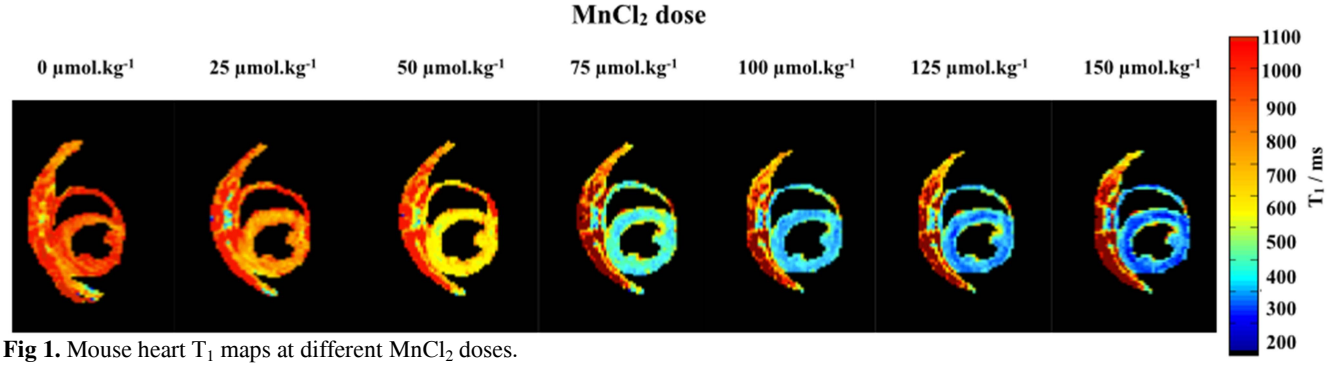

Fig 1. Mouse heart T_1 maps at different $MnCl_2$ doses.

RESULTS : In vitro results showed a good correlation with a relative difference lower than 5% between the T_1 measured with IR and our method. The r_1 of $MnCl_2$ was equal to 6.37mM.s^{-1} for IR and 6.40mM.s^{-1} for the new method. 3D T_1 maps were obtained for 5 mice. An average value of 1054±33 ms for the myocardium was measured without injection of contrast agent. The T_1 decrease was quantified during successive injections of $MnCl_2$ allowing to follow the manganese uptake in 3D as showed in **Fig1.a.** The averaged R^2 corresponding to the different $MnCl_2$ received doses was 0.93 ± 4 for all measured maps. 3D T_1 maps on ischemic mice also allowed to visualize the manganese bio-distribution in the whole heart. As targeted by the white arrows in **Fig2** the manganese ions did not penetrate the ischemic region.

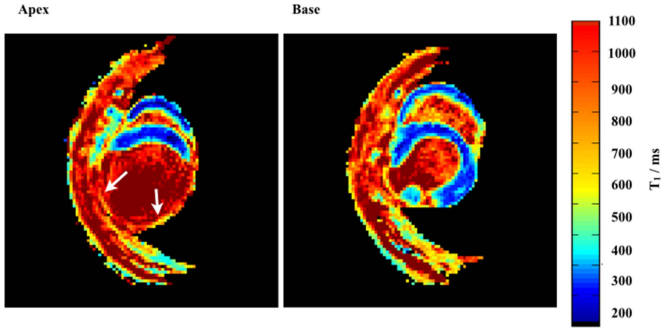

Fig 2. Post-contrast 3D T_1 map on ischemic mouse heart . White arrows target the myocardial lesions.

CONCLUSION : The method proposed in this project allows to obtain 3D T_1 maps in less than 12 minutes on a beating mouse heart with a high spatial resolution of 208 x 208 x 313 μm^3. In vitro experiments demonstrated both the accuracy and the precision of this approach to calculate the T_1 value in different vials . An averaged relative difference lower than 5% was found between the gold-standard inversion recovery and the alternative protocol proposed in this project. In vivo experiments demonstrated the efficiency of this protocol to quantify Mn^{2+} concentration in the whole mouse heart. This technique was validated for the detection of heart lesions induced by a myocardial infarction by using a Mn^{2+} injection.