Accurate T_1 Measurement with IR-prepared Segmented Gradient Echo and A New Regression Algorithm

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INTRODUCTION

There have been continuous interests trying to quantify myocardial blood flow with T_1-based arterial spin labeling in rodents [1]. The reliability of ASL in perfusion measurement is highly dependent on the accuracy of T_1. However, the myocardial T_1 measurement in small animals remains challenging because of the rapid heart rate and respiratory motion. In this study, we have modified an inversion recovery (IR) prepared, segmented gradient echo (GRE) sequence in Look-Locker scheme, and developed a new T_1 regression algorithm, aiming at increasing the T_1 accuracy. The accuracy of the T_1 with the proposed method was examined in a serial of agarose phantoms simulating the characteristics of myocardium and blood.

MATERIALS AND METHODS

Pulse Sequence: An adiabatic inversion pulse (non-selective (NonS) or selective (Sel)) followed by a α train segmented GRE readout in the Look-Locker scheme is developed to sample the T_1 recovery curve, which is also applicable for future studies in rodents. A delay of 2 s was insert after the last image to allow for full recovery of magnetization before the next IR.

T_1 Regression Algorithm: A multi-variable regression algorithm accounting for the saturation effect induced by the α-train at the center k-space line of each Look-Locker image was derived from Bloch Equation to predict T_1, which is adapted from the one originally developed for IR-prepared SNAPSHOT GRE [2]. The accuracy of this regression was compared to the conventional three-parameter T_1 fit algorithm [3], with the IR-prepared spin echo (SE) T_1 measurement as the gold standard.

MRI of Phantom: A serial of gel phantoms with varied concentrations of agarose and copper sulfate ($CuSO_4$) to simulate the T_1 and T_2 of human myocardium and blood prior and after Gadolinium contrast agent infusion (pre-calibrated with SE sequence at a clinical 1.5 T scanner) were used in our T_1 measurement . All studies were performed on a 7 T / 20 cm Bruker AVANCE III scanner (Billerica, MA), using the 72-mm volume coil. A single slice, IR-prepared segmented GRE imaging in Look-Locker scheme was acquired in axial position. Major imaging parameters included flip angle $\alpha=8^{o}$, TR=5 ms, TE=1.7 ms, FOV=60×60 mm, matrix size = 128×128, slice thickness=1.2 mm, number of Look-Locker images = 10, and segmented number = 4. IR-SE was also performed as the gold standard of T_1 measurement. RARE-VTE sequence was used to roughly predict the T_2 values of the phantoms.

Data Analysis T_1 of the phantoms was generated by the proposed multi-variable regression algorithm using the signal intensity from the IR-prepared segmented GRE image series. Also, conventional three-parameter fit of T_1 ($M=A-B^*\exp(-t/T_1^*)$, and $T_1^*= T_1^*$ $(B/A-1)$) was performed as comparison using the same signal intensities. The T_1 error of these two fit procedures were calculated by comparing with those measured from IR-SE, i.e., error= $(T_{1,IR-GRE}-T_{1,IR-SE})/T_{1,IR-SE}*100\%$.

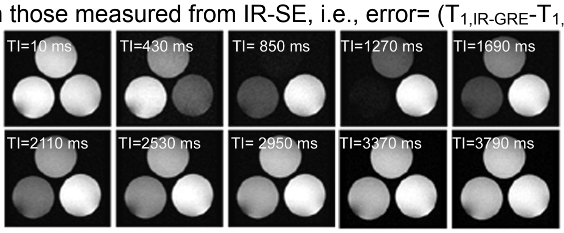

Fig. 1. Images at different TIs following the IR pulse obtained with our segmented GRE sequence.

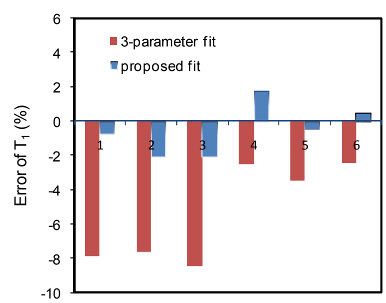

Fig. 2. Error of the T_1 fitted with the proposed regression algorithm and the conventional three-parameter algorithm, using the signal intensity from IR-prepared segmented GRE sequence in Look-Locker scheme.

RESULTS

A typical image series showing the signal change at different inversion time (TI) points following the IR pulse is demonstrated in Fig. 1. In the agarose phantoms simulating myocardium and blood (Table), using the segmented GRE acquisition, the T_1 measured from our proposed fitting algorithm (average error of -0.53%) is much closer to the actual values (from IR-SE), compared with the conventional three-parameter fitting (average error of -5.4%). The individual error of the two T_1 fitting algorithms, in comparison with the actual T_1, for the six phantoms studied is listed in Fig.2. Basically, the proposed fitting algorithm has corrected the underestimation of T_1 caused by the saturation effect in the three-parameter fitting, providing more accurate T_1s.

Table: Summary of the measured T_1 and T_2 for the phantom

Relaxation time (ms)	Myocardium		Blood	
	Before	After Gd	Before	After Gd
$T_{2,\ RARE-VTE}$	53.8	51.3	161.7	162.9
$T_{1,IR-SE}$	1234.4	361.4	1718.2	366.1
$T_{1,IR-GRE}$, three-parameter fitting	1191.8	332.9	1676.5	335.1
$T_{1,IR-GRE}$, proposed fitting	1228.4	358.7	1726.0	358.4

CONCLUSION

Using a modified IR-prepared segmented GRE sequence, together with a new T_1 regression algorithm that accounts for the saturation effect at the center k-space line in each Look-Locker image, a relatively more accurate T_1 measurement can be achieved in phantoms simulating myocardium and blood. With this accuracy of T_1 (-0.53% of error for T_1 in the physiological range of myocardium and blood), a reliable myocardial blood flow measurement by the T_1-based ASL is more likely to be achieved. The proposed T_1 measurement can also serve as a promising tool in other quantitative T_1 applications.

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