

# Accurate Myocardial T1 Measurements: Toward Quantification of Myocardial Blood Flow with Arterial Spin Labeling

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## INTRODUCTION

Myocardial blood flow (MBF) is a pathophysiological indicator of the microvascular alterations and can provide early-stage information of myocardial ischemia. Currently, first-pass perfusion has been widely used for the measurement of MBF, though it's dependent on the model and arterial input. Alternatively, there have been attempts trying to quantify MBF with arterial spin labeling (ASL) at steady-state [1]. However, the ASL is inhibited from wide use by its inadequate accuracy and less reliability. In this paper, we aimed to increase the ASL accuracy via a modified single shot gradient echo (GRE) sequence and a new T<sub>1</sub> regression algorithm. The accuracy of MBF measurements with the proposed method was examined in a canine model with and without coronary artery stenosis.

## MATERIALS AND METHODS

**Pulse Sequence and T<sub>1</sub> Algorithm** The sequence used in this study was an adiabatic inversion pulse (non-selective (Non-S) or selective (Sel)) followed by a  $\alpha$  train single shot GRE acquisition similar to Look-Locker style. Two initial inversion recovery times (TI<sub>1</sub>, 100 and 140 ms) were used to sample the T<sub>1</sub> recovery curve more finely. The sequence was performed in a sequential cascade format of Non-S(TI<sub>1,1</sub>)-Sel(TI<sub>1,1</sub>)-Non-S(TI<sub>1,2</sub>)-Sel(TI<sub>1,2</sub>). A multi-variable T<sub>1</sub> regression algorithm accounting for the saturation effect between image acquisitions was derived from Bloch Equation to predict more accurate T<sub>1</sub>. The accuracy of this method was first investigated in a phantom study.

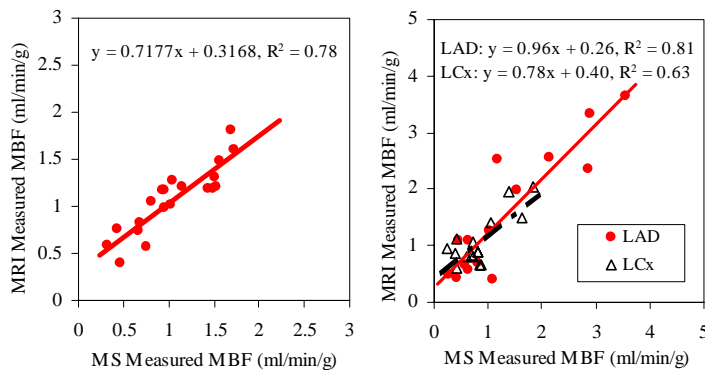
**Animal Preparation** Eight mongrel dogs (n = 8, 2 normal dogs and 6 dogs with induced 70% diameter narrowing of the left circumflex (LCx) coronary artery) were used in this study. The stenosis was introduced with an insertion of Teflon ring in the LCx coronary artery. Location and severity of the stenosis was confirmed by x-ray coronary angiography.

**MRI Procedure** All studies were performed in a 1.5 T Siemens Sonata system. After the scout image, a single slice imaging was acquired in the short-axis view of the heart at the middle ventricular level using the ASL pulse sequence described above within a single breath-hold. The data acquisition was triggered by the ECG signal of the dog and was obtained at mid-diastole, resulting in 6~8 images for each sequence, depending on the heart rate. With our sequential cascade of ASL acquisition, the duration of the breath-hold was 4\*(6~8)\*RR-intervals, ranging from 19~24 s. Other imaging parameters included flip angle  $\alpha=5^\circ$ , FOV=220 mm, slice thickness=8mm, TR=2.15 ms and number of k-space line n=64 and interpolated matrix size of 256 × 160. The ASL acquisition for the MBF calculation was performed at rest and during pharmacological induced vasodilation. The vasodilation was created by an intravenous infusion of dipyridamole at 0.15 mmol/kg/min continuously for 4 min. Color microsphere was performed simultaneously with the ASL acquisition as the gold standard of MBF measurement.

**Data Analysis** Pixel-wise T<sub>1</sub> maps of the dog were generated by the multi-variable regression fitting of signal intensity with the new algorithm. During the T<sub>1</sub> fitting, the TI for each image was based on the real clock time at which the central k-space was acquired, in order to partially correct the effect of irregular ECG and heartbeat. Then, pixel-wise MBF maps were calculated with the T<sub>1</sub> of left ventricular myocardium and blood pool (T<sub>1,Blood</sub>) [1]. In normal dogs, 4 regional ROIs were drawn on the MBF map in each dog; in stenotic dogs, 2 ROIs were drawn: one in the myocardium supplied by normal remote left anterior descending coronary artery (LAD) and one in the area perfused by stenotic LCx. Perfusion reserve was also calculated for all dogs. Regression analysis was performed between the MBF measured with ASL and color microsphere.

## RESULTS

In the phantom, the T<sub>1</sub> measured from our proposed ASL sequence with a selective inversion pulse was within 2.5% of the actual values (from IR-SE) using the proposed T<sub>1</sub> regression algorithm. Close agreement of MBF measured from the ASL and color microsphere was achieved in both normal and stenotic dogs (Figure). MBF at vasodilation and the perfusion reserve were higher in myocardium supplied by normal artery than those in area supplied by stenotic artery (Table). There was no statistical difference in MBF supplied by stenotic LCx region between rest and vasodilation (p>0.05). In contrast, there were significant differences of MBF in myocardium either in normal dogs or supplied by normal coronary artery in stenotic dogs.



**Figure:** Correlation analysis of the MBF measured from ASL and color microsphere. (a): Normal dog; (b) Stenotic dog.

**Table:** Summary of MBF measured by ASL

MBF (ml/min/g)	Normal dog	Stenotic Dog	
		LAD	LCx
Rest	0.61±0.15	0.79±0.29	0.85±0.17
Vasodilation	1.41±0.27	2.42±0.99	1.26±0.49
Perfusion Reserve	2.31±0.53	3.08±2.01	1.47±0.80

## CONCLUSION

Using a modified single shot GRE sequence with an adiabatic inversion pulse, together with a new T<sub>1</sub> regression algorithm that accounts for the saturation effect and certain cardiac arrhythmia, a relatively accurate T<sub>1</sub>-measurement can be achieved within a breath-hold. With this accuracy, a more reliable MBF is likely to be determined with the proposed method, as shown in a limited number of normal and stenotic dogs. The developed T<sub>1</sub>- and MBF-measurement techniques thus may serve as a promising tool to provide regional perfusion information at steady-state.

## ACKNOWLEDGEMENT

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## REFERENCES

1. Belle V, et al. J Magn Reson Imaging 1998; 8:1240-1245.