Dynamic Assessment of Myocardial Oxygen Consumption by MRI

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Introduction

Myocardial oxygen consumption (MVO_2) reflects total myocardial oxygen demand. Using deoxyhemoglobin as an endogenous contrast agent, we have demonstrated a novel method for dynamical assessment of myocardial oxygen extraction fraction (OEF) [1]. On the other hand, it is demonstrated by Bauer et al [2] that myocardial blood flow (MBF) can be quantified using an arterial spin labeling method (ASL) with measurements of both myocardial and blood T_1. Because MVO_2 can be quantified by Fick's law, i.e., $MVO_2 \propto OEF \times MBF$, the aims of this study are: (1) to develop MR methods for accurate measurement of both myocardial and blood T_1 in vivo; (2) to combine OEF and MBF measurements for dynamic quantification of MVO_2. The study was performed in a canine model with and without coronary artery stenosis.

Materials and Methods

Animal Preparation Three normal dogs were used for assessing global MVO_2 and three other dogs were scanned for the assessment of regional MVO_2 with induced coronary artery stenosis. The stenosis was introduced with an insertion of teflon ring (70% diameter narrowing) in the left circumflex (LCx) coronary artery. Heart rate and blood pressures were continuously recorded and the heart rate-pressure product (RPP) was used as the index of MVO_2.

MR Studies All studies were performed in a 1.5 T Siemens Sonata system. In each dog, image session consisted of studies at rest (baseline) and during pharmacological induced vasodilation. The latter was accomplished by an intravenous infusion of a dose of 0.15 mmol/kg/min of dipyridamole for 4 min. Only one short-axis slice of left ventricle (LV) was scanned. Both OEF and MBF data sets were acquired at rest and after the infusion of dipyridamole at different time points (10, 15, 20, and 30 min).

(1) *OEF measurement*: A 2D segmented multi-contrast turbo spin-echo sequence was used to acquire myocardial T_2 maps within a single breathhold. By measuring region-of-interest (ROI) on the T_2 maps, myocardial OEF can be calculated with our previously developed methods [1].

(2) *MBF measurement*: Myocardial and blood T_1 were measured with a look-locker style T_1 method [3]. A 2D single-shot turbo FLASH sequence was modified to acquire multiple images after a single inversion recovery pulse. Each image was obtained during the mid-diastole after an ECG signal. The TI for each image was determined based on the real time clock in the image stamp so that this T_1 measurement was insensitive to irregular ECG signals. Images with slice-selective and volume-selective inversion recovery pulses were acquired in an interleaved fashion. To accurately extract tissue T_1 values, a multi-variable nonlinear regression algorithm was developed. The T_1 method was evaluated in a phantom study and was found T_1 calculation error less than 2%. In all dogs, 5 types of color microspheres were injected at rest and during the vasodilation (10, 15, 20, 30 min) to validate the MBF measurement [2] by the ASL method.

Data Analysis A ring covering 50% of LV wall was drawn in the normal dogs for the quantification of global OEF, MBF, and MVO_2. In stenotic dogs, ROIs were located on both left anterior descending coronary artery (LAD) and LCx perfused segments. Student paired t-test were used to determine statistical difference in MBF values.

Results

In normal dogs (n=3), there is no statistically significant difference in MBF measured by MR ASL and microsphere methods. Dynamic MVO_2 values were plotted as a function of time after dipyridamole injections. It is clearly seen there is a close correlation between MVO_2 and RPP curves with a correlation coefficient of 0.85 (Figure). Table lists the dynamically measured MBF, OEF, and MVO_2 in both LAD and LCx segments in the stenotic dogs. Normal segment (LAD) shows 3-folder higher blood flow and nearly consistent MVO_2 change during dipyridamole-induced vasodilation. Due to moderate stenosis, MBF reserve in the LCx segment decreased and MVO_2 increased slightly during the vasodilation, but not statistically different from baseline values (0 min).

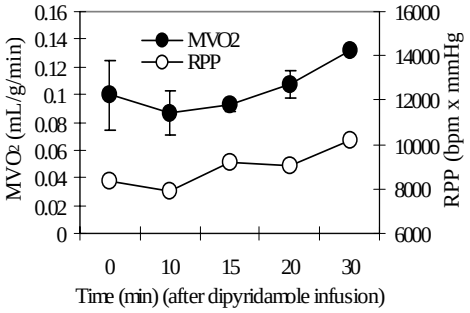

Figure. Myocardial oxygen consumption measured at rest and during dipyridamole induced vasodilation in normal dogs (n = 3).

Table

Time	MBF (mL/g/min) by MR		OEF by MR		MVO_2 (mL/g/min) by MR	
	LAD	LCx	LAD	LCx	LAD	LCx
0	0.93 ± 0.32	1.27 ± 0.83	0.70	0.70	0.12 ± 0.04	0.16 ± 0.11
10	2.28 ± 1.53	2.32 ± 0.90	0.19 ± 0.04	0.46 ± 0.11	0.08 ± 0.04	0.19 ± 0.01
15	2.37 ± 0.8	1.54 ± 0.44	0.17 ± 0.06	0.43 ± 0.1	0.08 ± 0.05	0.13 ± 0.06
20	3.00 ± 1.28	2.15 ± 0.41	0.23 ± 0.13	0.33 ± 0.12	0.12 ± 0.07	0.12 ± 0.04
30	2.30 ± 0.19	1.89 ± 0.13	0.30 ± 0.13	0.48 ± 0.18	0.12 ± 0.05	0.17 ± 0.07

Conclusion

We have demonstrated the feasibility of our MR approaches to detect myocardial consumption dynamically during pharmacologically induced vasodilation. This direct measurement of MVO_2 will allow consecutively monitoring dose-responses of myocardium to various therapeutic interventions. In clinical practice, dynamic evaluation of both MVO_2 and MBF will enhance our ability to elucidate the physiology and pathophysiology of the myocardial ischemia and viability.

Acknowledgement

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References

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