

T₂ Preparation Methods for the Quantification of Myocardial Oxygenation at Rest and During Hyperemia

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Purpose

We have recently developed a quantification MRI model to calculate the hyperemic myocardial oxygen extraction fraction (OEF) with the effect of myocardial blood-oxygen-level-dependence (BOLD) [1]. However, imaging acquisition had relied on the dark-blood turbo-spin-echo (DB-TSE) sequence to acquire myocardial T₂, which is sensitive to cardiac motion and arrhythmias. In addition, multiple 180° refocusing pulses in the TSE acquisition reduce the sensitivity of BOLD effect. The aim of this project was to evaluate a newly developed bright-blood T₂-prep-gradient-echo sequence (BB-T₂-prep-GE) for the quantification of myocardial OEF and oxygen consumption rate (MVO₂), at rest and during pharmacologically induced hyperemia, in a canine model. The DB-TSE sequence was used as well for comparison.

Methods

Eight beagles (wt = 9.4 ± 0.5 kg) were used for this feasibility study and divided into three groups with varied interventions (Table). Coronary artery stenosis was created by an adjustable occluder around the proximal left-anterior descending coronary artery (LAD) and stenosis severity was confirmed via Doppler flow reduction (90-100%). Both DB-TSE and BB-T₂-prep-GE sequences were performed at rest and during hyperemia. Previously, an assumed myocardial resting OEF of 0.6 was used for the calculation of hyperemic OEF. In this project, resting OEF was calculated using the blood T₂ in the coronary artery sinus (CS) using the BB-T₂-prep-GE sequence in three beagles to compare the findings with the assumed resting OEF. The pharmacological agent, dipyridamole, was infused intravenously over 4 min with a dose of 0.14mg/kg/min. The other stress agent, dobutamine, was infused intravenously at incremental doses of 5, 10, 20, or until the heart rate reached two-fold higher than the resting heart rate.

A BB-T₂-prep-GE sequence was designed to have either spin-echo or turbo-spin-echo type of T₂-prep, i.e., the number of 180° pulse in the 90°_x180°_y90°_x can be adjusted from 1. While increasing the number of 180° pulses will reduce the B₀ and B₁ inhomogeneity artifacts, the sensitivity of the sequence to the change of myocardial oxygenation would decrease as well. To calculate MVO₂ using Fick's law, $MVO_2 \propto OEF \times \text{myocardial blood flow (MBF)}$, MBF values, as well as blood volume (MBV), were quantified using a first-pass perfusion approach and a newly developed algorithm [2]. ROI measurements in the anterior (LAD subtended region) and remote posterior region were performed to calculate MBF, MBV, OEF, and MVO₂ using all of images acquired and aforementioned.

Results

Resting OEF in the CS was 0.6 ± 0.1. As expected, in normal dogs dobutamine causes a dramatic increase in MVO₂, while injection of dipyridamole shows only a moderate effect (Table). In the anterior area with 95% area stenosis, after the injection of dipyridamole, the MVO₂ in both anterior and normal posterior regions were blunted, while minor changes in hyperemic OEF were observed only in the anterior region. Both the BB-T₂-prep and DB-TSE sequences yielded similar results in OEF and MVO₂ (no statistical analysis was performed due to limited subject number). However, the sensitivity for 100% MBF increase was approximately 3.1% using the DB-TSE sequence and 20% using the BB-T₂-prep-GE sequence. Less flow artifacts were associated with the T₂-prep sequence and the T₂-prep with three 180° pulses provided the best image quality (Figure).

Conclusions

For the first time, a T₂-prep method is used for the quantification of myocardial OEF and MVO₂, both at rest and during hyperemia. The image quality, sensitivity, and precision appear equal or superior to the DB-TSE sequence. Further study is warranted to determine its accuracy.

References

1. Zheng J, et al. Magn Reson Med 2004;51:718-26.
2. Goldstein TA, et al. Magn Reson Med, 2008; 59: 1394-1400.

Table The MRI findings in 7 dogs with a variety of interventions. Hyperemic MVO₂ was calculated using OEF from BOLD TSE sequence. DIP = dipyridamole, DOB = dobutamine, numbers in parentheses = standard deviation

Dogs	DIP/ DOB	Hyperemic OEF (BOLD TSE)		Hyperemic OEF (T2prep)		Resting MVO ₂ (μmol/g/min)		Hyperemic MVO ₂ (μmol/g/min)	
		ANT	POS	ANT	POS	ANT	POS	ANT	POS
Normal (n=2)	DIP	0.20 (0.14)	0.27 (0.24)	0.26 (0.16)	0.25 (0.20)	6.6 (0.1)	7.2 (0.4)	6.0 (5.9)	9.2 (10.2)
Normal (n=2)	DOB	0.43 (0.17)	0.44 (0.23)	0.44 (0.1)	0.40 (0.06)	7.0 (1.5)	6.9 (2.3)	14.0 (0.1)	12.0 (0.8)
95% LAD (n=3)	DIP	0.52 (0.17)	0.32 (0.17)	0.55 (0.17)	0.32 (0.14)	6.7 (2.9)	9.3 (1.2)	5.5 (0.7)	7.5 (4.6)

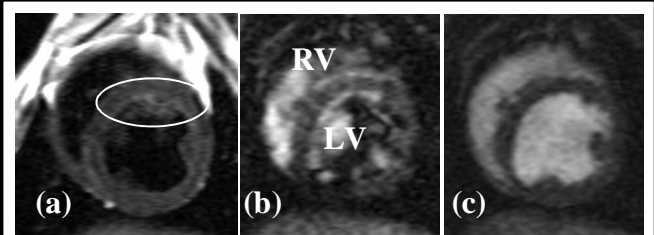


Figure The CMR myocardial images in one dog using different sequences: (a)DB-TSE; (b)BB-T2prep-GE with only one 180° pulse in T2prep module; (c) BB-T2prep-GE with three 180° pulses in T2prep module. White circle in (a) indicates flow artifacts. All images were acquired at TE of 72 ms