

Non-contrast Measurement of Myocardial Perfusion and Oxygenation by MRI: Comparison with PET in an acute Coronary Stenotic Canine Model

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Introduction

Under physiological conditions, myocardial blood flow (MBF), myocardial oxygen extraction fraction (OEF), and oxygen consumption (MVO₂) are intimately related. Myocardial ischemia exists when the supply of oxygen to the myocardial tissue is inadequate for the metabolic oxygen demand of myocardium. MRI has shown the capability to non-invasively image MBF and myocardial oxygenation. The aim of this work is to perform an initial study for the evaluation of previously developed MRI methods [1,2] to measure MBF and MVO₂ without using contrast agents, in a comparison with PET measurements in an acute coronary stenotic canine model.

Materials and Methods

Animal Models Six mongrel dogs (23.4 ± 1.4 kg) were used and single coronary artery stenosis was created in the proximal to middle portion of the LAD (n = 5) or LCx (n = 1) artery by an intracoronary Teflon ring. The diameter reduction in the LAD was approximately 50-60% to induce sufficient ischemia to impair myocardial perfusion reserve. The details were presented in the report [2]. The dogs were first scanned by PET and then transferred to MRI suite for imaging in the same day. During both imaging sessions, dobutamine was infused to alter MVO₂ and MBF.

PET Imaging Protocols All PET studies were performed on Siemens 962 HR+ whole-body tomographs. The electrocardiogram, arterial blood pressure, and blood gas values were monitored throughout the procedure. A transmission scan was performed to correct for photon attenuation. ¹⁵O-water (up to 1.0 mCi/kg) was administered as an intravenous bolus and dynamic PET data was acquired for 5 minutes to measure the resting MBF. After the decay of ¹⁵O radioactivity, ¹¹C-acetate (40 mCi/kg) was administered as a bolus and 30 minutes of dynamic data collection occurred to determine the resting MVO₂ measurements. Venous blood samples were obtained at regular intervals to determine the ¹¹CO₂ concentrations. After the ¹¹C radioactivity decay, stress was induced by intravenous infusion of an initial dose of 10 µg/kg/min dobutamine and increased at 5 min intervals to 20, 30, and a maximum of 40 µg/kg/min (if the heart rate was over 130 beats/min). The same procedure was followed to determine stress MBF measurements. A return to baseline was followed by another infusion of dobutamine to perform the stress MVO₂ levels.

MRI Imaging Protocols All MR imaging was performed on a 1.5-T whole-body Sonata system (Siemens Medical Solutions, Erlangen, Germany). The dogs were positioned supine, and ventilated with a gas mixture of 100% oxygen and room air. Scout imaging was performed to obtain a short-axis image of the LV at the middle level of the papillary muscle. Cine MRI was performed at rest to determine the motionless period during the cardiac cycle. T₂-weighted MRI was performed in the same section location at rest and during dobutamine stress induced in the same fashion as PET. A previously reported technique was applied to calculate myocardial OEF. In addition, arterial spin labeling (ASL) method [1] was also performed to measure single-slice MBF at rest and during dobutamine stress. The ASL method performed measurements on MBF by measuring myocardial T₁ values with preparations of slice-selective and volume-selective inversion or saturation pulses.

Data Analysis For PET images, data reconstruction was performed on a Sun workstation for image analysis with a home-made image-analysis software package. Myocardial images were reformatted to the true short-axis views on which measurements of perfusion and metabolism will be performed. Three regions of interest (ROIs) (anterior, lateral, and posterior) will be drawn on a PET image corresponding to the MR image slice to generate myocardial and blood time activity curves for each set of tracer data. Regional MBF (mL/g/min) will be quantified with a well established kinetic model. A one-compartment kinetic model was applied to estimate the rate at which ¹¹C-acetate is converted to ¹¹CO₂ (k₂, min⁻¹). Regional MVO₂ (µmol/g/min) was then determined using a previously published relationship between k₂ and MVO₂ [3]. Once the MVO₂ and MBF are known, the regional OEF can then be calculated by means of Fick's law. Three ROIs was also drawn on the original MR T₂-weighted and T₁-weighted images to calculate OEF and MBF. MVO₂ was calculated according to Fick's law. Correlations of measurement results between MRI and PET was then determined.

RESULTS

Because of some severe motion artifacts during dobutamine stress MRI session, some MR data (MBF or OEF) in 4 dogs was excluded for further analysis, resulting in comparable (MRI vs PET) data sets for MVO₂ (n = 4, two dogs at rest and during stress), MBF (n = 6), and OEF (n = 5). The correlations were shown in Fig. 1. Both PET and MRI shows comparable decreases in myocardial flow reserve in stenotic perfusion segments, but changes in the OEF and MVO₂ (similar or decreases in OEF and increases in MVO₂ from rest to stress) remain the same between stenotic and normal perfused myocardial beds, as consistently observed by both PET and MRI images.

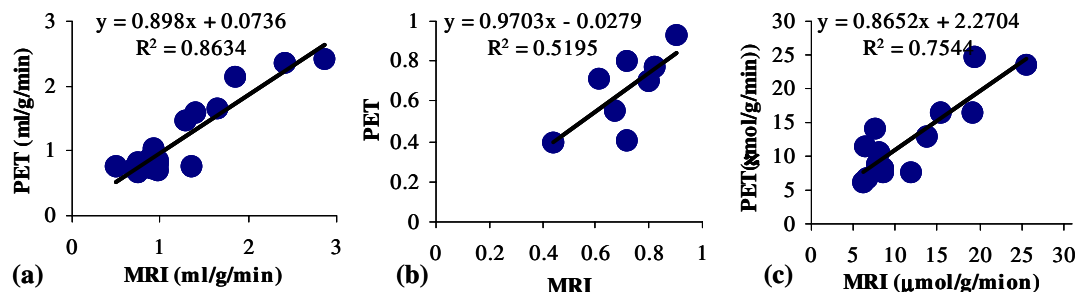


Figure 1. (a) MBF; (b) OEF; and (c) MVO₂. MBF and MVO₂ by MRI agree well with PET results, whereas OEF shows moderate correlation between two image modalities.

CONCLUSION

Our results indicate it is feasible to perform relatively accurate measurements by non-contrast MRI methods (ASL and BOLD imaging). MRI slightly overestimated PET data. Further effort to improve the accuracy of OEF measurement is needed. These techniques will need rigorous validation in animal models that produce MVO₂-deficit during the dobutamine stress.

REFERENCES

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3. Herrero P, et al, J Nucl Med 1996;37:161.