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Quantification of myocardial perfusion based on signal intensity of flow sensitized MRI

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Summary

A new method to quantify myocardial perfusion was developed based on slice select (M_S) and non-select (M_G) inversion recovery acquisitions at a single inversion time. A modified Bloch equation was solved to obtain an analytical expression for perfusion (P) in terms of $\Delta M_{SG} = M_S - M_G$ The average myocardial perfusion of healthy C57BL/6 mice measured using this technique (P=5.7±0.4 ml/g/min) agreed with that measured using traditional techniques and it had a high reproducibility with mean standard deviation of 3.6% between repeated measures. Perfusion maps of ischemia-reperfusion mice showed significantly low perfusion (P=1.6±0.3 ml/g/min) in the infarcted regions compared to that of remote regions (P=4.1±0.3 ml/g/min,p=0.004).

Background

The arterial spin labeling technique based on the T1 relaxation time of tissue (T1 method) can be used to quantify myocardial perfusion without the use of exogenous contrast materials[1]. However accurate estimation of T1 relaxation times in the heart, especially in mice is difficult and can require long scan time. As an alternative, we developed a method to quantify myocardial perfusion based on the signal intensity(SI method)of flow sensitized MRI.

Methods

Myocardial tissue was modeled as intra and extra vascular compartments with fast exchange of spins in between them[1]. The flow sensitization was achieved by slice select (M_S) and non-select (M_G) inversion recovery acquisitions at a single inversion time. A steady state gradient echo image (Msa) was also acquired to normalize receiver characteristics. A modified Bloch equation was solved for this acquisition scheme to obtain an analytical expression for perfusion (P) in terms of $\Delta M_{SG} = M_S - M_G$ as follows:

$P = \langle \Delta M_{SG}(t).\lambda / M_{sa}(t) \rangle / (2\text{-}Exp(-TR/T_{1c})\text{-}TI/T_{1c}).T1$

where T_{1c}=relaxation time of blood,λ=spin density ratio and T1=tissue relaxation time. After validating with flow phantoms (data not shown) the SI method was compared with the conventional T1 method in healthy C57BL/6 mice (n=12). A repeated in vivo experiment was carried out to test the reproducibility of the SI method. Finally, quantitative perfusion maps were obtained in a mouse model of ischemia-reperfusion (n=4) in comparison to delayed Gd enhancement. All experiments were performed on a Bruker 7T scanner and gated gradient echo IR-FLASH and IR- Lock Locker sequences were used for SI and T1 methods with TE=1.7ms, FOV=2.5×2.5cm2, matrix size=128×64, slice thickness=2mm and TR (SI method)≈10×RR, TR(T1 method)≈40×RR.

Results

The mean left ventricular perfusion in mice derived from the SI method (P=5.7±0.4 ml/g/min) agreed with that obtained from the conventional T1 method (P=5.6 ±0.3 ml/g/min) and that quantified with fluorescent microspheres (P=5.7±0.3 ml/g/min)[2]. SI method had a high reproducibility with mean standard deviation of 3.6% between repeated measures. Perfusion maps of ischemia-reperfusion mice showed (Figure 2) significantly low perfusion (P=1.6±0.3 ml/g/min) in the hyper intense regions of the corresponding delayed enhanced image compared to remote regions (P=4.1±0.3 ml/g/min, p=0.004).

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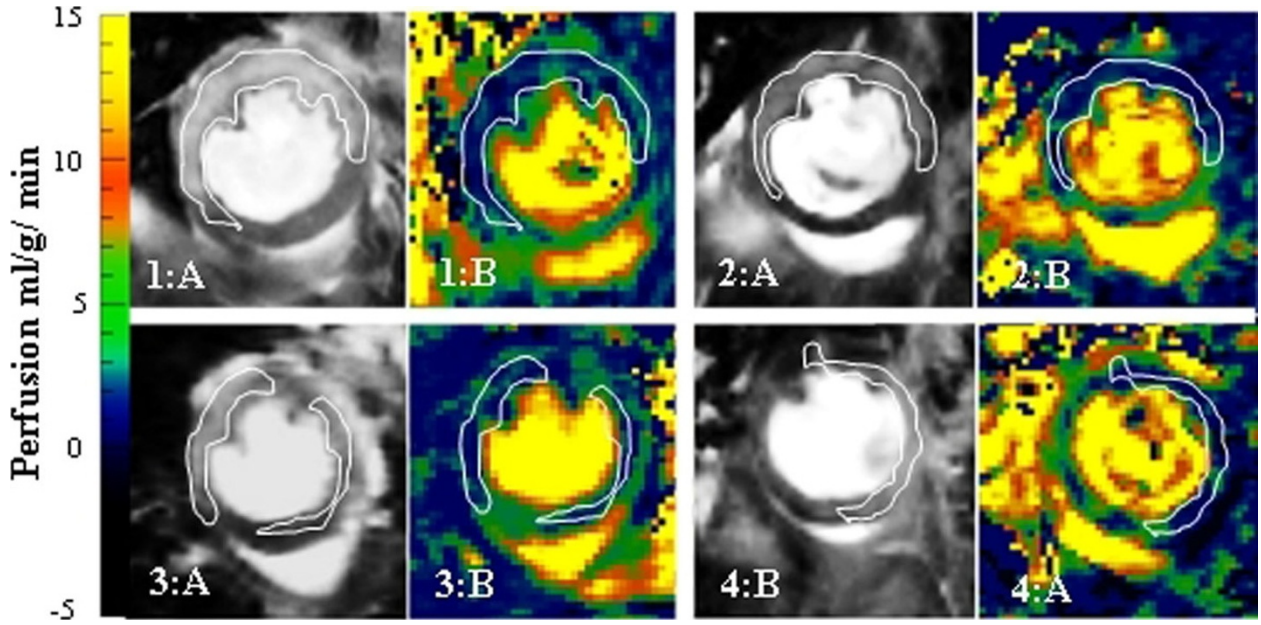

Figure 2 Perfusion deficit regions (right) corresponded well with the myocardial delayed enhancement (left).

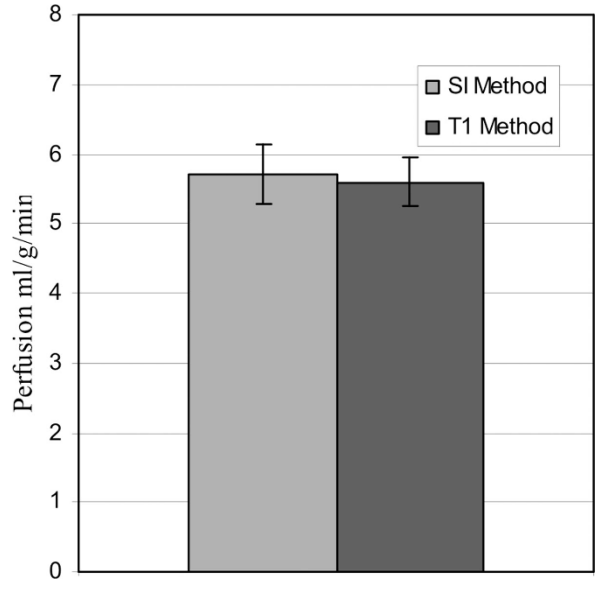

Figure 1 Comparison of SI and T1 methods for myocardial perfusion.

Conclusions

The SI method for perfusion is a robust alternative to the conventional T1 method. In mice it reduces scan time considerably (30%-40%) and is highly reproducible.

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