Cine-ASL: new arterial spin labeling method for myocardial perfusion mapping in mice using a Cine-FLASH labeling and readout module

Thomas Troalen¹, Thibaut Capron¹, Monique Bernard¹, Patrick Cozzone¹, and Frank Kober¹

¹Centre de Résonance Magnétique Biologique et Médicale (CRMBM), UMR CNRS N°6612, Faculté de Médecine, Aix-Marseille Université, Marseille, France

Introduction

The quantitative assessment of myocardial perfusion is of high potential for the diagnosis and therapeutic follow-up of various cardiac pathologies, and non-ischemic heart disease in particular. Arterial spin labeling (ASL) has been developed and used to quantitatively map rodent myocardial blood flow (MBF) for more than a decade (1-2). There is growing interest in improving sensitivity and measurement strategy, because accurate and motion-robust acquisitions are still time-consuming with typical measurement times of about 20 minutes (3). Here, we propose to combine a continuous Cine-MRI gradient echo readout with a steady-pulsed arterial labeling approach, which leads to a perfusion-dependent stationary regime. This original scheme significantly improves ASL sensitivity while maintaining compatibility with motion constraints in cardiac MRI in small rodents.

Methods

The new sequence was implemented on a Bruker Biospec 4.7T MR system using an ECG-gated Cine-FLASH sequence as a basis. As shown in figure 1, one echo in each cine block was substituted by an inversion pulse, labeling the arterial blood in a slice covering the aortic arch and atria (T) at a precise timing within the cardiac cycle. The sequence was repeated over several cardiac cycles in order to reach the steady-state of a FLASH experiment under the influence of perfusion. A control scan (C) was achieved by placing the inversion slab in symmetry to the short-axis imaging

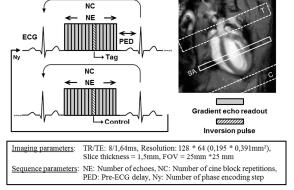


Figure 1

plane (SA), compensating for magnetization transfer effects. Interleaved tag and control acquisitions are performed for each k-space line with a total acquisition time of 8 minutes at 500 bpm. MBF measurements were performed in twenty female C57BL/6 mice (weight 25–29g) anesthetized with 1.5% isoflurane added to 1 L min⁻¹ of pure O₂. For comparison, both the new Cine-ASL scheme (acquisition time 8min) and a Look-Locker-FAIR gradient echo ASL (LLFAIRGE) measurement was performed (acquisition time 24 minutes). In two mice, both experiments were also performed under two different isoflurane concentrations (1.5% and 2%) to verify the response of both techniques under vasodilation. A theoretical model developed for this Cine-ASL sequence shows that during each acquisition block (control and tag), a steady state magnetization is rapidly reached at which the magnetization difference between tag and control scans depends explicitly on perfusion. This model was used to quantify MBF from the data obtained in mice.

Results and Discussion

Good concordance was observed between myocardial perfusion assessed with the new Cine-ASL technique $(6.5 \pm 1.3 \text{ ml g}^{-1} \text{ min}^{-1})$ and LLFAIRGE $(7.3 \pm 1.5 \text{ ml g}^{-1} \text{ min}^{-1})$ in the n=20 animals, although Cine-ASL had a tendency to lower values. Under 2% isoflurane, perfusion consistently increased by a factor of about 3 in both studied animals. All MBF values were in agreement with previous studies (3, 4). One current limitation of this sequence is related to the geometrical complexity of the heart and its function. Indeed, the tagging slab covers three areas (both atria and aorta) such that blood entering the coronary system has been inverted several times. Our experiments showed that even though adiabatic inversion pulse were used for this tagging scheme, blood magnetization at the entry of the coronary system is in a saturated rather than in an inverted state. Despite this loss in tagging efficiency, the new sequence showed significantly better acquisition efficiency than LLFAIRGE leading to comparable mapping quality within one third of the acquisition time.

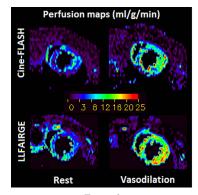


Figure 2

We present a new ASL tagging and readout scheme to quantify MBF in vivo in mice. The scheme is shown here to be more sensitive than the previously employed FAIRLLGE method. In addition to shorter acquisition time, this technique has the further advantage of being feasible with short transmit coils because it does not rely on global inversion of a large volume of blood. The steady-state Cine-FLASH readout module also allows for averaging of the steady perfusion-dependent magnetization difference over several cardiac cycles to improve SNR, or alternatively to study magnetization difference changes across the cardiac cycle.

References

Conclusion

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