

Journée scientifiques

Nouvelles Méthodologies en Imagerie du Vivant

Lyon, décembre 2012

Cyclic Variation of Myocardial Blood Flow Assessed with cine-ASL

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Frank Kober

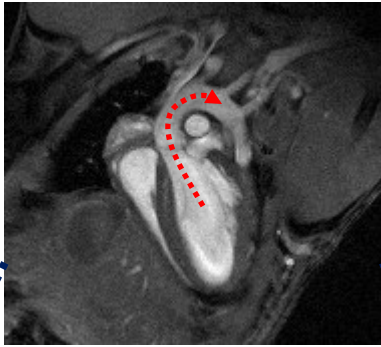
Centre de Résonance Magnétique Biologique et Médicale,
CRMBM, Aix-Marseille Université, France



The cardiac cycle

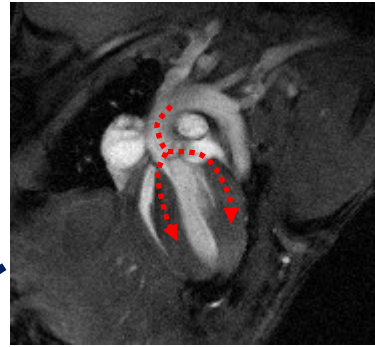
Systole

Ventricular ejection: movement of blood from left ventricle to the ascending aorta



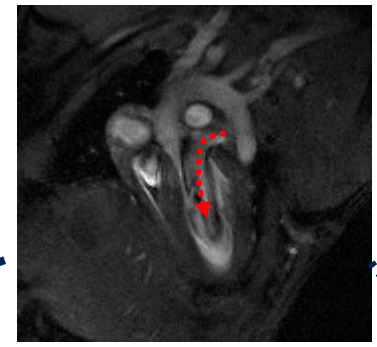
End-Systole / Early-Diastole

The whole heart is relaxed
Aortic valve closure at ES/ED due to the blood pressure in the aorta

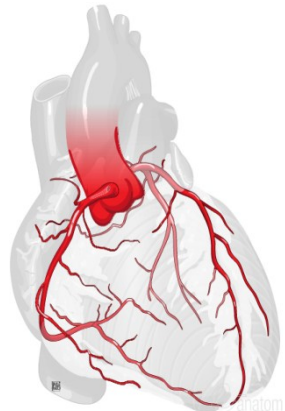


Diastole

Ventricular filling: atrium contracts and blood flows from atrium into ventricle



R ← → R

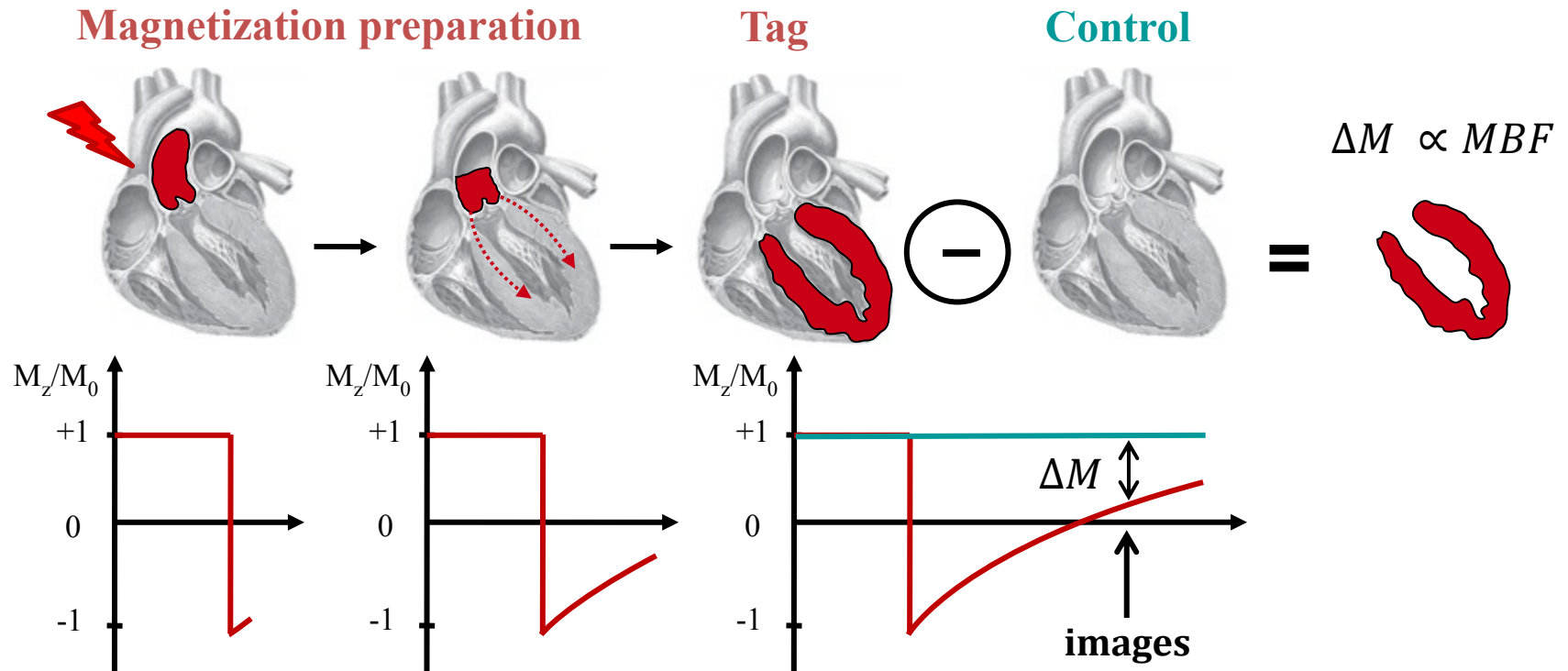


Coronary Blood Flow

- No arterial inflow during systole. Overall vascular space decreases and coronary vessels are compressed due to high intravascular pressure.
- Most arterial inflow occurs during diastole when coronary vessels are patent and under low pressure.

Arterial Spin Labeling

- Quantitative measurement of tissue blood flow ($\text{mL g}^{-1} \text{min}^{-1}$)
- Use an endogenous tracer: the blood itself
- Based on the subtraction of two images



ASL signal is inherently proportional to Myocardial Blood Flow (MBF)
Completely non-invasive, reproducible and repeatable



Low Signal to Noise Ratio (SNR)

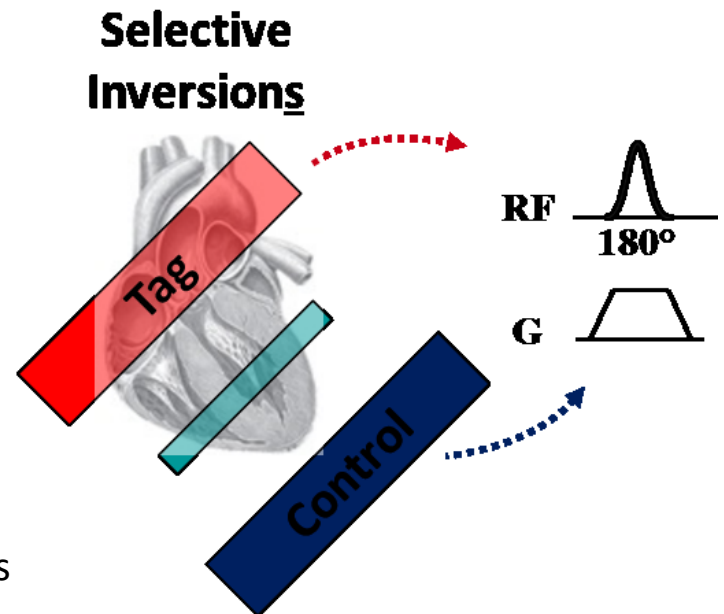
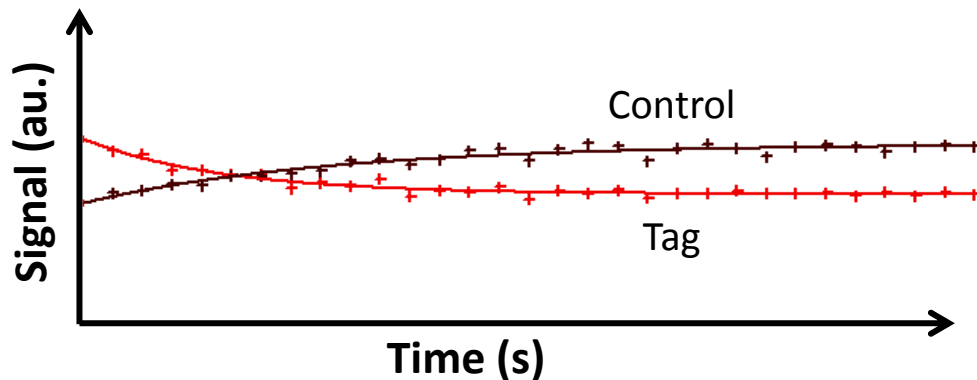
cine-ASL

New ASL method to map myocardial blood flow:

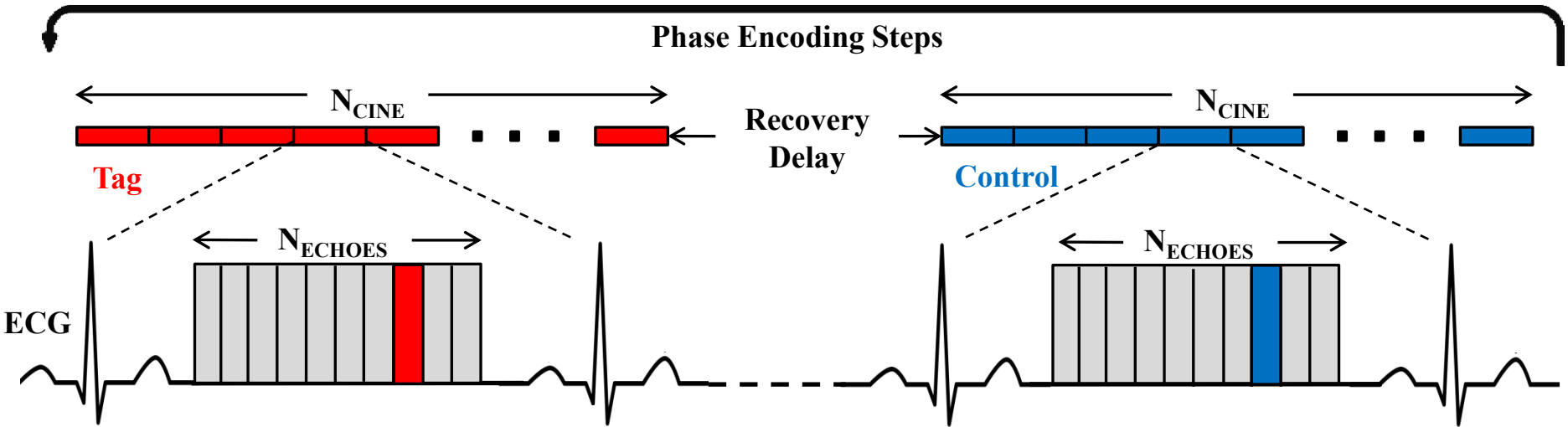
Combination of continuous cine-MRI gradient echo readout with steady-pulsed arterial labeling

Features:

- One tag event per heart beat
- FLASH steady-state under the influence of perfusion
- Control necessary to compensate for magnetization transfer effects



cine-ASL MR Pulse Sequence

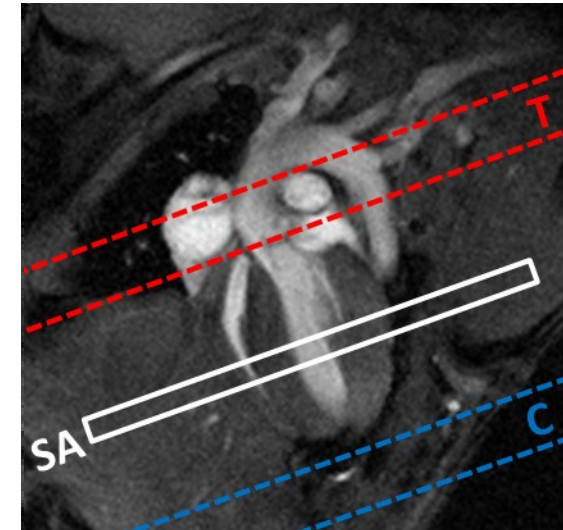


Main advantages of using a steady-pulsed labeling scheme:

- > The labeling is maintained as long as the sequence is running
- > Improve ASL sensitivity for heart studies
- > Stationary regime of the magnetization *

$$MBF = \frac{\lambda M_{SS}}{T_1^* M_0} \frac{\frac{\Delta M_{\infty}}{M_{\infty}^c}}{2\beta - \frac{\Delta M_{\infty}}{M_{\infty}^c}}$$

M_{SS} FLASH steady-state
 T_1^* Apparent relaxation time
 λ Blood/Tissue partition coefficient
 β Labeling efficiency

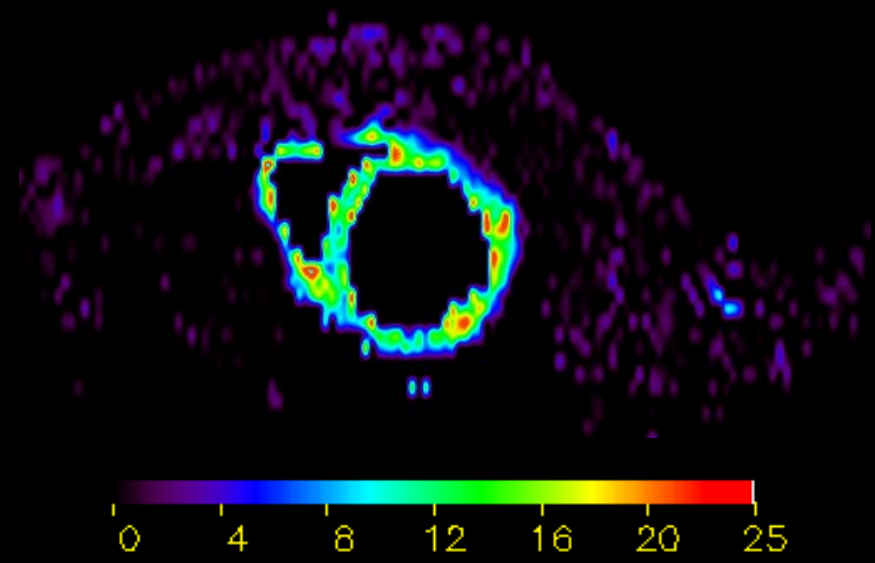
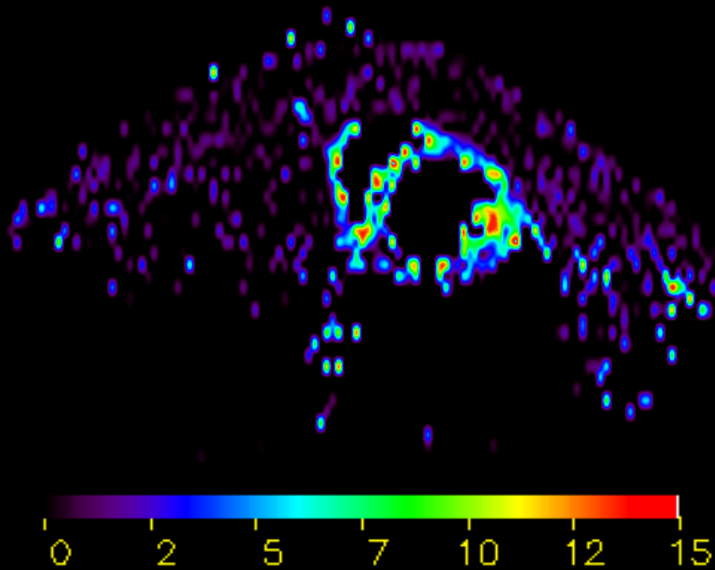


Dynamic mapping across the cardiac cycle

Myocardial Blood Flow

Mouse at rest

Rat under adenosine-induced stress



Absolute quantification in mL g⁻¹ min⁻¹

Earlier observations (1)

Cyclic blood volume change in mice Wu, et al. JMRI 2004

- First mapping of cyclic change in myocardial blood volume.
- 16.2% decrease from End-Diastole (ED) to End-Systole (ES) in the lateral wall, 24.7% in the septum.

JOURNAL OF MAGNETIC RESONANCE IMAGING 19:50-58 (2004)

Original Research

Mapping Cyclic Change of Regional Myocardial Blood Volume Using Steady-State Susceptibility Effect of Iron Oxide Nanoparticles

Ed X. Wu, PhD,^{1*} Haiying Tang, PhD,¹ Kelvin K. Wong, MSc,^{1,2} and Jie Wang, MD, PhD³

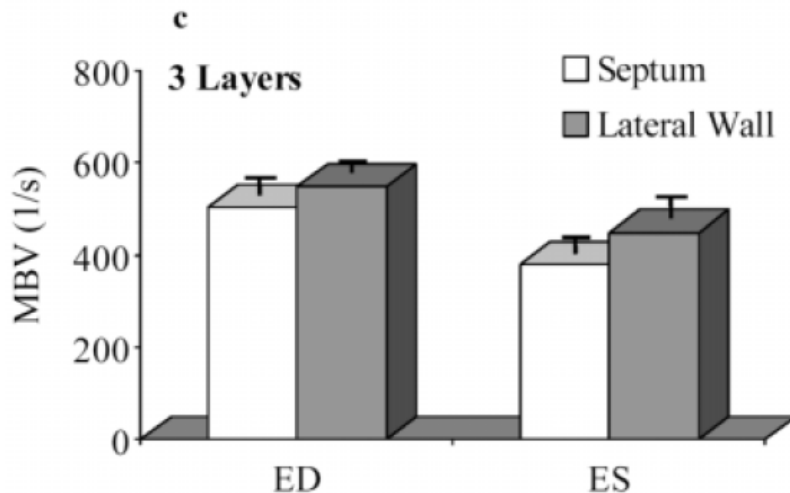


Figure 5. Average regional MBV or ΔR_2^* values in the septum and lateral wall at three transmural layers at ED (a) and ES (b). Average MBV values in the entire septum and lateral wall (c) are also shown.

Earlier observations (2)

Cyclic blood flow in humans (DCE)

Radjenovic, et al. MRM 2010

- ES and ED myocardial blood flow estimation by DCE.
- No statistical change at rest ($1.6 \text{ mL g}^{-1} \text{ min}^{-1}$ vs. $1.7 \text{ mL g}^{-1} \text{ min}^{-1}$)
- Significant increase (25%) at ED under adenosine-induced vasodilatory stress
 - > $4.3 \text{ mL g}^{-1} \text{ min}^{-1}$ at ES vs. $5.7 \text{ mL g}^{-1} \text{ min}^{-1}$ at ED

Magnetic Resonance in Medicine 64:1696–1703 (2010)

Estimates of Systolic and Diastolic Myocardial Blood Flow by Dynamic Contrast-Enhanced MRI

Aleksandra Radjenovic,^{1*} John D. Biglands,¹ Abdulghani Larghat,¹ John P. Ridgway,² Stephen G. Ball,¹ John P. Greenwood,¹ Michael Jerosch-Herold,³ and Sven Plein¹

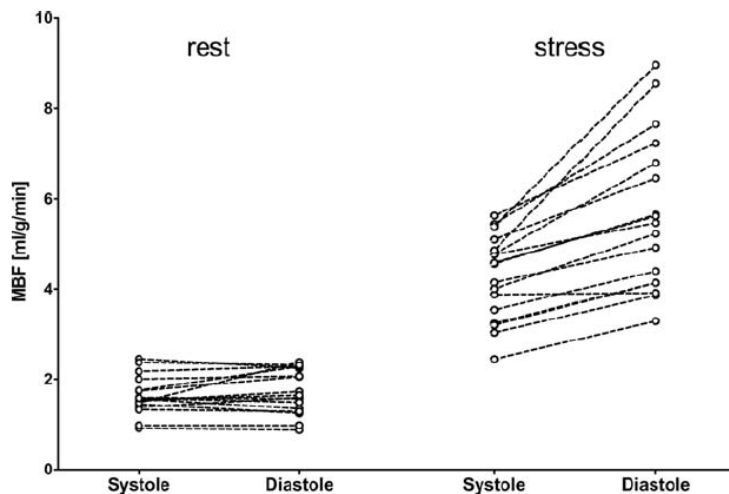
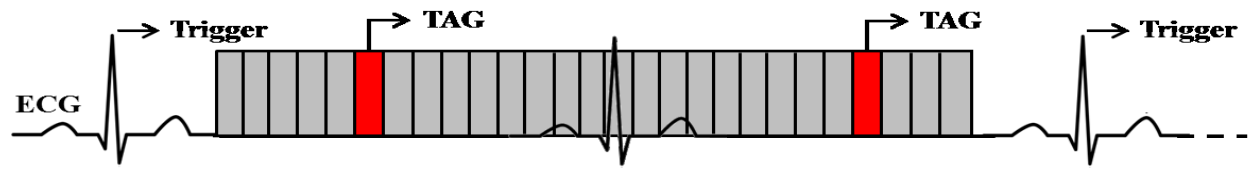


FIG. 5. Transmural myocardial blood flow estimates at rest and under adenosine stress in systole and diastole in 17 healthy volunteers.

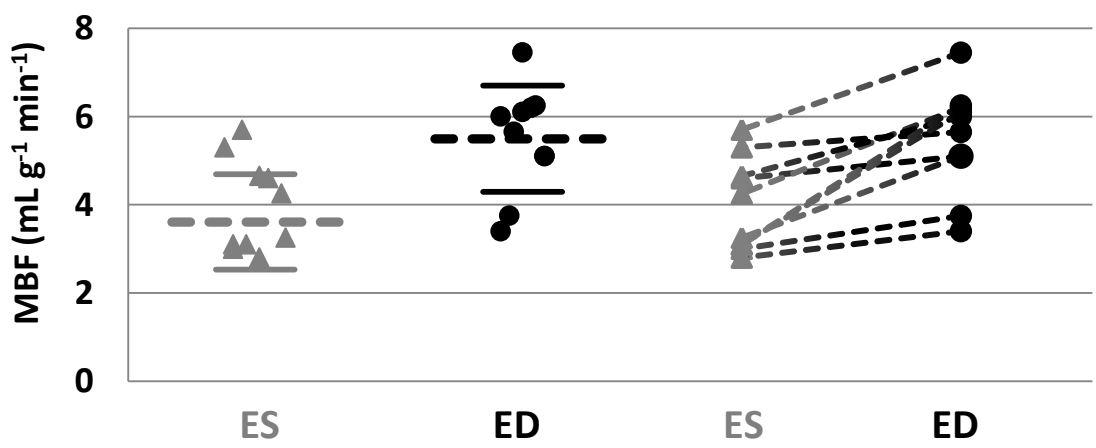
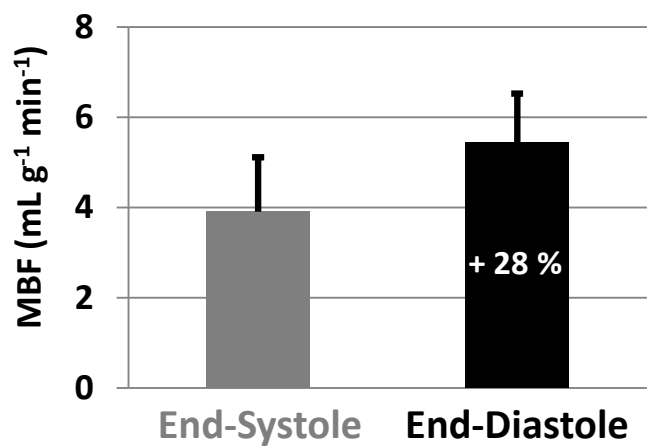
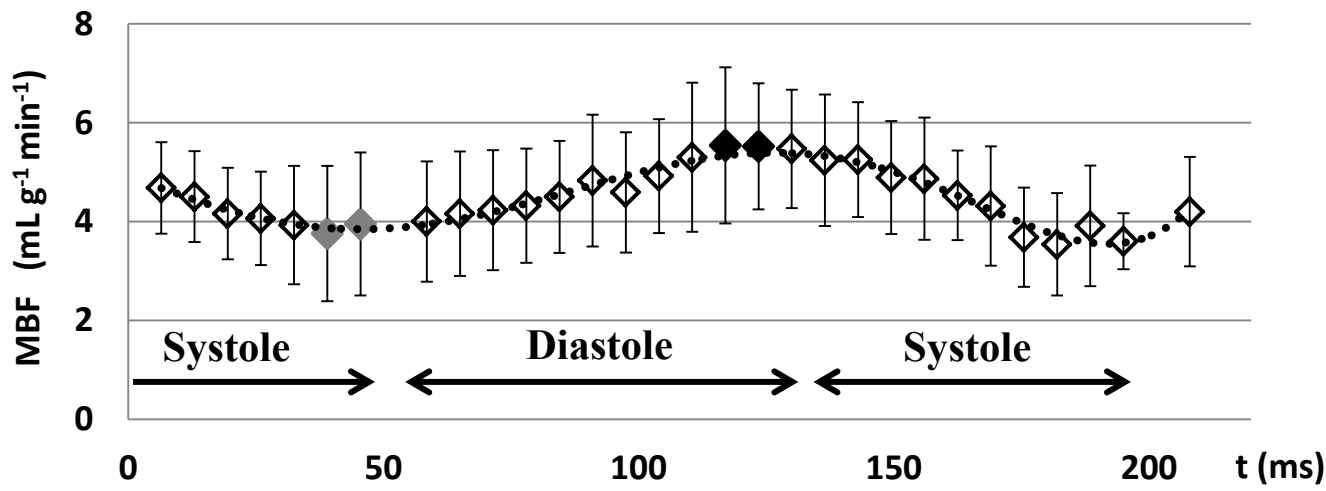
Dynamic mapping -> Cyclic variation



Our observations in ten mice (anterior myocardium ROI)

10 C57Bl/6 mice

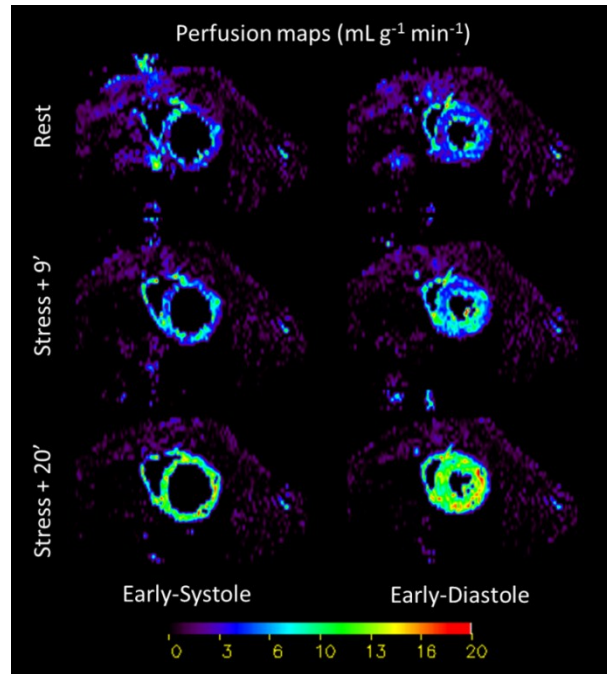
- Bruker Biospec 4.7T
- Anesthesia: 1.5% isoflurane
- Fov: 25 x 25 mm²
- Resolution: 195 x 391 μm²
- Acq. time: 14 min
- Mean heart rate: 139 ± 16 ms



Cyclic variation at rest & during stress

1 Wistar Rat

- Bruker Biospec 4.7T
- Anesthesia: 1.5% isoflurane
- Fov: 25 x 25 mm²
- Resolution: 195 x 391 μm²
- Acq. time: 8 min
- IV adenosine perfusion
 - > 140 μg/kg/min
- Heart Rate: 400 bpm / 150 ms



Rest

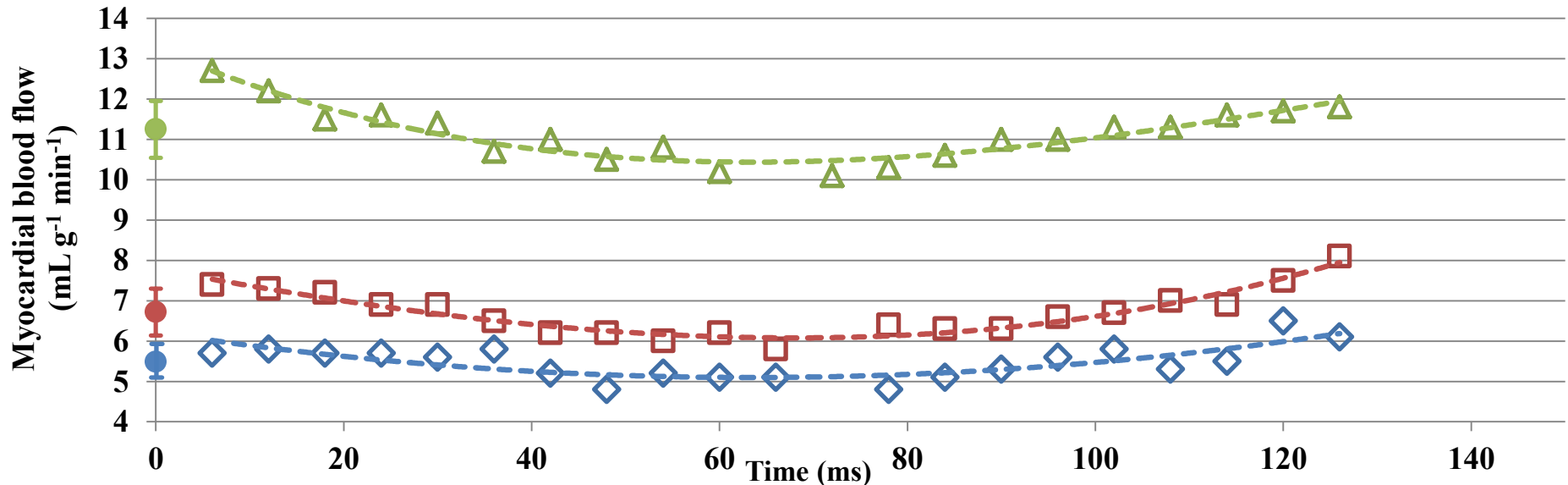
$5,5 \pm 0,4 \text{ mL g}^{-1} \text{ min}^{-1}$
 $\Delta\text{MBF} = 32\%$

Stress + 9'

$6,7 \pm 0,6 \text{ mL g}^{-1} \text{ min}^{-1}$
 $\Delta\text{MBF} = 28\%$

Stress + 20'

$11,3 \pm 0,7 \text{ mL g}^{-1} \text{ min}^{-1}$
 $\Delta\text{MBF} = 21\%$



Conclusion

- New ASL tagging and readout scheme for absolute quantification of myocardial blood flow with good sensitivity
- Cine-ASL allows for dynamic mapping of MBF *in vivo* across the cardiac cycle with high spatial and temporal resolution
- Cyclic variation of regional MBF can now be measured using MRI

Perspectives:

- Study dynamic blood flow variation within the cardiac cycle on rats at rest and during adenosine-induced stress
- Might give contribution to studies of the transport of blood through the myocardial tissue

Acknowledgments

CRMBM Methodology Team:

- Thibaut Capron
- Frank Kober
- Monique Bernard



Thank you for your attention !