Comparison of systolic and diastolic myocardial perfusion by dynamic contrast enhanced MRI

A. Radjenovic[1], J. D. Biglands[1], A. Larghat[1], J. P. Ridgway[1], M. Jerosch-Herold[2], J. P. Greenwood[1], and S. Plein[1]
[1]School of Medicine, University of Leeds, Leeds, England, United Kingdom, [2]Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States

Introduction: Myocardial blood flow (MBF) varies during the cardiac cycle in response to pulsatile changes in epicardial circulation and cyclical variation in myocardial tension. First-pass assessment of myocardial perfusion by dynamic contrast-enhanced MRI (DCE-MRI) is one of the most challenging applications of MRI, due to the nature of spatial and temporal constraints imposed by the cardiac physiology and the nature of DCE-MRI signal collection. These constraints are particularly severe under vasodilatory stress conditions. Conventionally, differences in myocardial blood flow in the cardiac cycle are therefore not considered in DCE-MRI. Here we describe a DCE-MRI method for parallel assessment of systolic and diastolic MBF and its zonal distribution at rest and under adenosine induced vasodilatory stress.
Method: Imaging was performed with a 1.5T whole body magnetic resonance scanner (Intera CV, Philips Medical Systems, Best, The Netherlands). The pulse sequence details were as follows: saturation recovery prepared single-shot gradient echo with two-fold SENSE, TR/TE/φ 2.7ms/1.0ms/15°, FOV 320mm, image matrix 160x160, in-plane spatial resolution 2mm x 2mm, slice thickness 10mm, preparation pulse delay (to middle of k-space) TP = 150ms, acquisition duration 135ms (with half scan and 80% RFOV). Slice positioning and the timing of acquisition were designed to image a single mid-ventricular short axis slice in two cardiac phases. Appropriate trigger delays were selected using the individual heart rate, high temporal resolution (30 phases) cine MRI, and by taking into account the expected shortening of the R-R interval under adenosine stress. Seventeen healthy volunteers (8 women, 9 men; mean age, 34 years; age range, 24–48 years) were scanned during maximal vasodilatation obtained by injection of adenosine at a dose of 140 µg/min/kg for 4 minutes (stress DCE-MRI) followed by a rest DCE-MRI fifteen minutes later. For each perfusion acquisition a contrast injection at a dose of 0.05 mmol/kg gadopentetate dimeglumine (Magnevist, Bayer Schering Pharma) was administered at a rate of 5ml/s. In DCE-MRI datasets endocardial and epicardial contours were traced using dedicated cardiac image analysis software (MASS 6.1, Medis, Leiden, The Netherlands). Manual correction for respiratory motion was applied. The arterial input function (AIF) was derived from a region of interest placed within the left ventricular cavity. The MBF was quantified from the left ventricular AIF and myocardial tissue signal intensity (SI) curves derived from systolic and diastolic data using a Fermi constrained deconvolution method [1]. In order avoid potential effects of variations in the AIF between systole and diastole, the same (systolic) AIF was used for analysis of both diastolic and systolic MBF. In addition to analysing transmural MBF estimates from myocardial SI curves derived from the entire area between the endocardial and epicardial borders, zonal distribution of MBF was assessed by subdividing the LV wall into three concentric zones: sub-endocardial (endo), middle (mid) and sub-epicardial (epi). Statistical analysis of the differences between systolic and diastolic estimates of MBF and myocardial perfusion reserve (MPR) was performed using a paired t-test and the analysis of zonal MBF values was performed using a repeated measures ANOVA test with Bonferroni correction for multiple comparisons (all at $\alpha = 0.05$ confidence level).

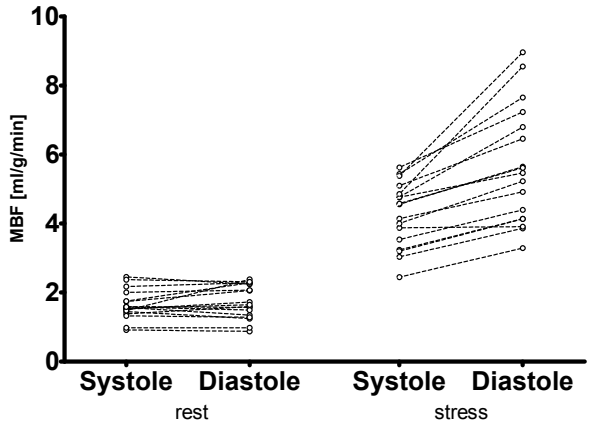

Figure 1. Transmural MBF estimates at rest and under adenosine stress in systole and diastole in seventeen healthy volunteers.

		endo		mid		epi	
		Mean	SD	Mean	SD	Mean	SD
Rest	**Systolic MBF**	1.8	0.49	1.7	0.46	1.5	0.42
	Diastolic MBF	1.9	0.67	1.6	0.40	1.6	0.39
Stress	**Systolic MBF**	4.1	0.75	4.5	0.91	4.7	1.2
	Diastolic MBF	6.2	2.2	5.4	1.7	5.3	1.5
	Systolic MPR	2.4	0.53	2.8	0.46	3.1	0.55
	Diastolic MPR	3.3	0.76	3.3	0.75	3.3	0.72

Table 1. Summary of zonal MBF [ml/g/min] and MPR estimates, (n = 17)

Results: Transmural MBF: All values are expressed as mean ± SD. MBF is quoted in units of ml/g/min. Resting transmural MBF estimates were similar at 1.6 ± 0.42 and 1.7 ± 0.49, $p>0.05$ in systole and diastole respectively (Figure 1). At stress MBF was significantly different at 4.3 ± 0.93 (systole) and 5.7 ± 1.7 (diastole), $p < 0.0001$. Myocardial perfusion reserve, computed as a ratio of stress and rest MBF estimates was also significantly different between systole and diastole at 2.7 ± 0.84 in systole and 3.4 ± 0.75 in diastole, $p < 0.001$.
Zonal MBF: Systolic and diastolic MBF values for the three myocardial zones (endo/epi/mid) showed significant differences at rest and stress, both in systole and diastole, with ANOVA $p<0.005$, (Table 1). Paired subendocardial and subepicardial MBF values were significantly different at stress and rest in systole and diastole. Subendocardial MBF was higher than subepicaridal MBF, apart from the systole at stress where this relation was reversed with significantly lower subendocardial MBF than subepicardial MBF (4.1 ± 0.75 vs 4.7 ± 1.2, $p<0.01$). Zonal analysis of MPR detected no significant differences in diastole, but a significantly lower subendocardial than subepicardial MPR in systole (2.4 ± 0.53 vs.3.1 ± 0.55, $p<0.001$).
Discussion: Parallel assessment of myocardial perfusion using DCE-MRI is feasible. Estimates of hyperaemic MBF differ significantly between systole and diastole, following the expected physiological pattern of preferential diastolic filling.
Our results show that MBF is independent of the cardiac phase at rest (Table 1 and Figure 1). This is in agreement with limited earlier observations [2,3]. However, under adenosine induced vasodilatation, MBF and MPR are significantly higher in diastole than in systole. Furthermore, subendocardial to subepicardial distribution of MBF (and MPR) is cardiac phase dependent, with the reversal of MBF gradient under stress in systole, but not diastole in normal myocardium (Table 1).
The observed difference between systolic and diastolic MBF must be taken into account when assessing MBF using DCE-MRI. Furthermore, targeted assessment of systolic or diastolic perfusion using DCE-MRI may provide novel insights into the pathophysiology of ischaemic heart disease.
References: 1. Jerosch-Herold M. et al. Med. Phys. 1998; 25(1):73:84;
2. Shin T. et al. Proc. Intl. Soc. Mag. Reson. Med. 17 (2009), p. 1771;
3. Jerosch-Herold M. et al. JMRI 19:758–770 (2004).