Early diastolic function observed in canine model of reperfused transmural myocardial infarction using high temporal resolution MR imaging

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Introduction: Coronary angioplasty limits infarct expansion post myocardial infarction (MI). However, under certain conditions such as prolonged ischemia, the procedure induces reperfusion injury (RI), linked to adverse left ventricular (LV) remodeling and heart failure (HF). The functional mechanisms involved in adverse remodeling post reperfusion are still unclear. We have developed a new high temporal resolution MR imaging technique, SPAMM-PAV (SPAtially Modulated Magnetization with Polarity Alternated Velocity encoding) that provides regional assessment of early diastolic flow velocity and myocardial strain [1]. This method was applied in a canine animal model with prolonged occlusion followed by reperfusion. We examine the diastolic strain-rates, elastic modulus and viscosity of infarct regions relative to remote regions 3 days post reperfusion to provide insight into early diastolic function in these animals.

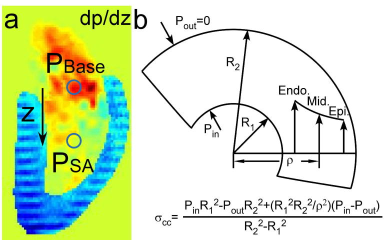

Fig 1. *(a) Color-coded longitudinal pressure gradient maps with LV tagging mask overlaid. (b) Thick-wall cylindrical stress calculation model, with formula using to compute the circumferential stress illustrated. P_{SA} shown in (a) is same as P_{in} in (b).*

Methods: First, the HARP method was used to compute the Lagrangian circumferential strain and strain-rate from the tagged images [2]. With the understanding that a larger HARP bandwidth yields a sharper strain response, we employed CANSEL [3] as the acquisition scheme to elimintate the dc peak and the other harmonic peak and selected a HARP filter bandwidth of 96 pixels. Second, to compute circumferential stress, the gradient between the pressures of the sampled short-axis slice, P_{SA}, and the base, P_{Base}, (see Fig. 1a) is initially computed from the velocity fields using Euler's equations. In this study, P_{Base} is not measured but obtained from the literature. Two values of P_{Base}, 7.4 and 13.7 mmHg, which respectively correspond to published LV early and end diastolic pressures [4], are used. A thick-wall cylindrical model, as shown in Fig. 1b, was implemented to calculate the circumferential stress, where $P_{in}=P_{SA}=P_{Base}+ z\cdot(dp/dz)$ (Fig. 1a) and $P_{out}=0$. Finally, the time dependent changes in wall stress $\sigma(t)$ and wall strain $\varepsilon(t)$ was related using the Kelvin–Voigt constitutive relationship, $\sigma(t) = E\varepsilon(t) + \eta(d\varepsilon(t)/dt)$, to calculate the Young's modulus of elasticity and viscosity.

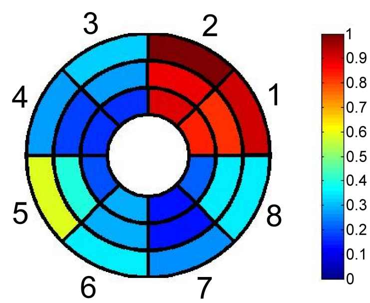

Fig. 3. *Bulls eye plot depicting relative Young's modulus of elasticity of a short-axis slice. Eight regions are segmented with three transmural layers separated.*

Experiments and Results: Studies were performed in six dogs following 5-6 hours of balloon occlusion of the left anterior descending artery (LAD) followed by reperfusion creating an antero-septal transmural infarct (see Fig. 2a) with reperfusion injury (see Fig. 2b). SPAMM-PAV measurements for both in-plane directions were conducted on a 1.5T scanner on six short-axis slices and two long-axis slices, with imaging parameters set as follows: imaging matrix: 192×192, resolution: 1.5mm×1.5mm, slice thickness: 8mm, views per cardiac phase: 3, tag separation: 8mm, Venc: 120-150 cm/s, temporal resolution: 15ms. Late gadolinium enhancement imaging was performed to detect infarct region, and first pass perfusion imaging was performed to detect regions of microvascular obstruction due to RI. Diastolic strain and strain-rates were computed from acquired SPAMM-PAV datasets using HARP analysis methods.

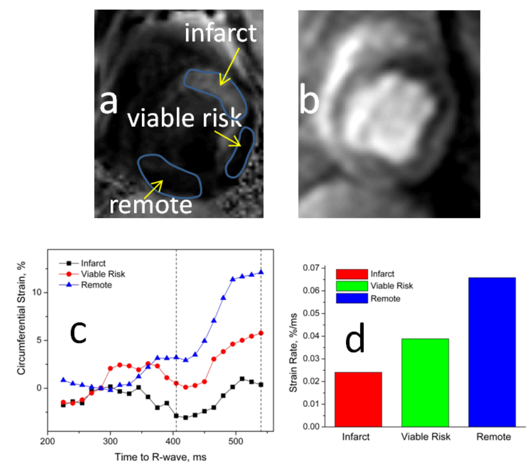

Fig 2. *(a) Delayed hyper-enhanced image depicting infarct zone, and (b) corresponding first pass perfusion image depicting region of micro-vascular obstruction. (c) average diastolic strain curves and (d) average diastolic strain-rates in regions defined in infarct, viable risk and remote zones*

The delayed hyper-enhancement image obtained 10-min post injection of Gd-based contrast agent (Magnevist) of a short-axis slice is illustrated in Fig. 2a where the infarct, viable risk and remote regions are empirically defined. The correspondent first-pass perfusion image is shown in Fig. 2b with the micro-vascular obstruction region indicated. The average circumferential diastolic strain and strain-rate in these three regions of this slice are shown in Figs. 2c and 2d. Note decreased diastolic strain-rates in infarct and viable risk regions, indicating increased stiffness in these regions. A bulls-eye map of relative Young's modulus of elasticity, E, at a 3 day time point for this animal is shown in Fig. 3. Note increased stiffness in infarct regions correlating to decreased strain-rates observed in these regions as shown in Fig. 2d. The average values of computed modulus of elasticity and viscosity for eight segments and three layers as defined in Fig. 3 are shown in Table 1. While infarct regions exhibit significant increase in modulus of elasticity, no significant trend in the distribution of viscosity is observed.

	Regions	1		2		3		4		5		6		7		8	
		1*	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Endo-layer	E (kPa)	0.19	0.37	0.231	0.445	0.0811	0.154	0.0252	0.0461	0.0481	0.0905	0.0911	0.172	0.11	0.204	0.0803	0.149
	η (Pa·s)	0.78	1.3	0.75	1.3	0.93	1.7	0.02	0.008	0.14	0.33	0.59	0.95	0.63	1	0.6	1
Mid-layer	E (kPa)	0.259	0.493	0.258	0.487	0.0603	0.114	0.109	0.189	0.0624	0.119	0.115	0.217	0.0989	0.184	0.0859	0.16
	η (Pa·s)	1.2	2.4	0.55	0.33	0.79	1.3	0.47	0.86	0.59	0.87	1.5	2.4	0.7	1.2	0.088	0.16
Epi-layer	E (kPa)	0.285	0.53	0.206	0.385	0.131	0.243	0.212	0.391	0.0568	0.107	0.121	0.231	0.0848	0.157	0.088	0.163
	η (Pa·s)	1.2	2.2	3.3	5.6	0.3	0.55	2.1	4	0.28	0.35	1.4	2.3	0.43	0.77	0.084	1.5

Table 1. *Elasticity, E, and viscosity, η, of 8-segment endo-, mid- and epi-layers of the sampled short-axis slice through Kelvin-Voigt relationship.*Cases 1 and 2 respectively represent the situations that P_{Base} is assigned with a value of 7.4 and 13.7 mmHg.*

Conclusion: In conclusion, in a canine model of reperfused transmural infarction we observe decreased diastolic strain-rates, as well as high modulus of elasticity, in the infarct and to some extent in viable risk regions relative to remote regions at 3 days post reperfusion.

Reference: 1. Zhang Z, et. al., Magn Reson Med; 2011, DOI:10.1002/mrm.22965. 2. Osman NF et al. , Magn Reson Med, 42 (1999) 1048-1060. 3. Epstein FH and Gilson WD, Magn Reson Med, 52 (2004) 774–81. 4. Cao JJ, et. al., Circ Cardiovasc Imaging; 2011, DOI: 10.1161/CIRCIMAGING.110.959569.