Assessment of Left Ventricular 2D Pseudo Flow Pathway during Early Diastole Using SPAMM-PAV

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Introduction: The objective of our study is to shed insight on regional early diastolic filling mechanics in the left ventricle (LV) through 1) the tracking of 2D pseudo pathlines of blood emitter particles dynamically released from the mitral valve plane, and 2) the study of its correlation with regional myocardial relaxation patterns. Current clinical assessment of diastolic dysfunction relies heavily on measurements of mitral valve inflow velocity (E/A) ratios, which are not reliable and susceptible to pseudonormal measurement during disease progression [2, 3]. We have developed a new high temporal resolution MR imaging technique, SPAMM-PAV (SPAtially Modulated Magnetization with Polarity Alternated Velocity encoding) that provides *simultaneous* regional assessment of flow velocities and myocardial strains during early diastole [4] (see Fig. 1.). Using this method, we studied 2D pseudo flow pathlines and their relation to regional myocardial relaxation in order to provide more sensitive detection of diastolic dysfunction.

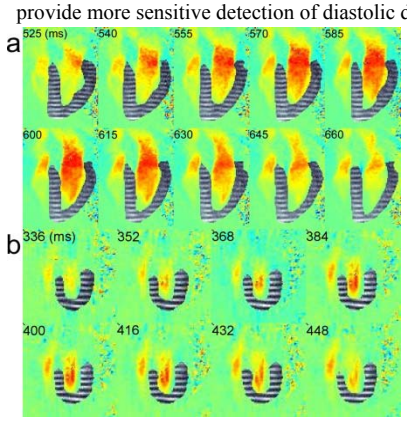

Fig.1. *Tagged myocardium with super-imposed longitudinal velocity maps for a 4-chamber slice in a (a) Normal volunteer, and (b) Infarted dog.*

Methods of MR Imaging: We performed experiments in five normal (i.e., no prior diagnosis or symptoms of any heart disease) volunteers [3 females, 2 males; age: 34 ± 9 (mean ± SD) yrs; height: 1.73 ± 0.09 m; weight: 69.39 ± 14.23 kg] and an infarted dog. SPAMM-PAV measurements were conducted on a 1.5 T scanner. Imaging parameters were 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: 15-16ms. Parallel imaging with accelerating factors of 2 and 4 were respectively set for volunteer and dog studies, resulting in acquisition times of 32 s and 16 s.

2D Pseudo Flow Pathways: A set of blood emitter particles directly proportional to the area under the mitral inflow velocity curve (red rectangular area in Fig. 2.) were released from the valve plane at each time frame. Next, from 2D SPAMM-PAV datasets, the flow velocity pseudo pathlines of each set of released emitter particles was tracked as illustrated in Fig. 3. The pathlines are color-coded according to the bar in Fig. 2. to highlight the particle evolution in time. The superposition of these pathlines in a single visual display is illustrated in Fig. 4. Additionally, regional myocardial longitudinal strain evolution was computed from SPAMM-PAV datasets.

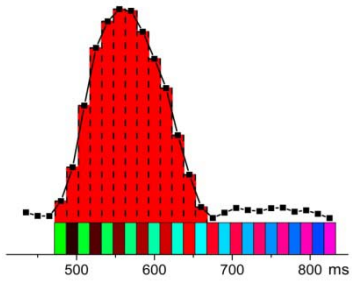

Fig 2. *Mitral inflow velocity curve. Area under the curve at each time interval is used to determine number of blood particles emitted at each time frame in Fig. 3. The color bar with alternated contrast is used in Fig. 3. to highlight the time evolution of the emitted blood particles.*

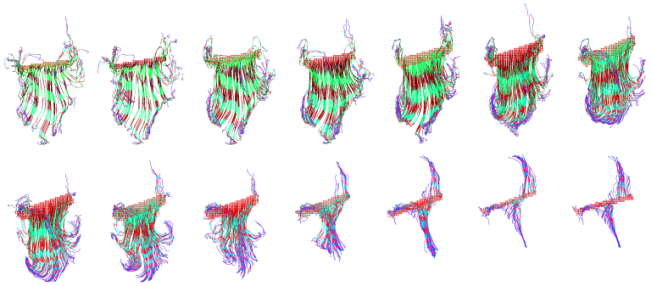

Fig 3. *The flow pathways of each set of emitting particles investigated in terms of both route and step length. A wavefront like propagation is observed. Blood propagating into LV at an early stage distributes uniformly throughout the LV, while blood entering at later frames contributes to a more centric filling (away from the walls and the apex).*

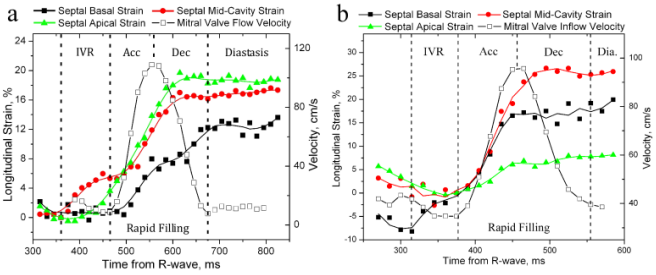

Fig 5. *Time plots comparing average longitudinal strain in basal, mid-cavity, and apical regions of septal wall during diastolic phases of isovolumic relaxation (IVR) , rapid filling (acceleration and deceleration), and early diastasis for (a) normal volunteer in Fig. 1a, and (b) infarcted dog in Fig. 1b. Mitral valve inflow velocity curve is superimposed as a temporal reference.*

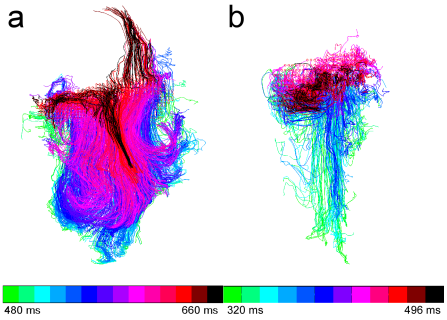

Fig 4. *Overlapped blood emitter particle flow pathways for (a) Normal volunteer and (b) Infarted dog, color-coded to indicate time at which each set of blood particles are emitted.*

Results: Fig. 1 depicts the high temporal resolution tagged myocardium with superimposed longitudinal velocity maps in a four chamber slice for a normal volunteer and a dog with a septal infarct. Using SPAMM-PAV, clear visualization of impaired diastolic relaxation in the septum and abnormal filling patterns are observed in the infarcted animal.

A more detailed analysis of the flow pattern evolution in a normal volunteer during early diastole is illustrated in Fig. 3. Blood propagates through the LV in a wavefront like fashion moving towards the apex (see Fig. 3). From Fig. 4a, we observe that blood entering during early time frames spread uniformly, but at later frames have pathlines that are gradually restricted away from the apex and the walls. During the deceleration phase, the blood mostly contributes towards basal filling. These results correspond closely with the regional strain results in Fig. 5, where apical strain rates are highest during the acceleration phase, while basal relaxation dominates during the deceleration phase. As illustrated in Fig. 4b, a significant abnormality in the filling pattern of the infarcted dog is observed. Here, the blood from earlier frames propagates down to the apex, and blood entering at later frames stagnates in the basal region.

Conclusion and Ongoing Work: From our preliminary studies in normal volunteers and an infarcted dog, 2D pseudo flow pathlines are sensitive to abnormalities in early diastolic filling, and may provide a reliable diagnostic indicator of diastolic dysfunction.

References: [1] Eriksson J, et al. J Cardiovasc Magn Reson 2010, 12:9; [2] Hartiala J, et al. Am Heart J 1993, 125: 1054; [3] Beppu S, et al. Circulation 1988, 78:157; [4] Zhang Z, et al. ISMRM Cardiovascular Flow, Function and Tissue Mechanics conference, Sintra, Portugal, 11-13 Sep, 2009; [5] Markl M, et al. J Magn Reson Imaging 2007, 25:824.