Quantification of Pre-Systolic Left Ventricular 4D Blood Flow Organization in Normal and Failing Hearts

J. Eriksson[1], P. Dyverfeldt[1], J. Engvall[1], A. F. Bolger[2], T. Ebbers[1], and C-J. Carlhäll[1]
[1]Linköping University and Center for Medical Image Science and Visualization (CMIV), Linköping, Sweden, [2]University of California San Francisco, San Francisco, California, United States

Introduction: The evaluation and diagnosis of heart disease is most commonly based on morphology and often with one-directional flow assessment using ultrasound Doppler. Previously, we presented a pathlines analysis method for the quantitative assessment of the 4D blood flow that transits the human left ventricle (LV) [1]. Here we extend this approach to the assessment of pre-systolic LV blood flow organization in order to evaluate the preparation of different flow components for systolic outflow in healthy subjects and patients with idiopathic dilated cardiomyopathy (DCM).

Method: Six healthy subjects (3 female, mean age 58 [range 50-61] years) and seven patients (4 female, mean age 52 [range 22-62] years) with DCM underwent MRI examination including a three-directional, three-dimensional cine phase-contrast MRI (3DcinePC-MRI) sequence during free breathing, using a navigator gated gradient-echo pulse-sequence with interleaved flow encoding segments on a clinical 1.5 T scanner (Philips Achieva) [2]. Scanning parameters included VENC: ±100 m/s, voxel size: 3x3x3 mm^3, and temporal resolution: 50 ms. Corrections were made for concomitant gradient field effects, residual background phase errors and phase wraps. Additionally, a stack of short axis balanced steady state free precession (bSSFP) images was acquired.

Using the pathlines analysis method [1], the LV blood flow was separated into four components: *Direct Flow* = Blood that enters and leaves the LV during the analyzed cardiac cycle. *Retained Inflow* = Blood that enters the LV during the analyzed cardiac cycle and does not leave during systole of the analyzed heart beat. *Delayed Ejection Flow* = Blood that starts within the LV and leaves during systole of the analyzed heart beat, and *Residual Volume* = Blood that resides within the LV for the entire analyzed cardiac cycle [3]. In short, this is achieved by combining morphological data with pathlines describing all flow that transits the LV during one cardiac cycle (Figure 1).

At IVC, the distance (*IVC distance*) from the position of the trace to the center of the LV outflow tract (LVOT) was calculated for all particles. At the same point in time, the angle (*IVC angle*) between the velocity vector of each particle trace and the vector directed towards the center of LVOT was also calculated.

Results: The LV ejection fraction was smaller and LV end-diastolic diameter was larger in DCM compared to healthy subjects (43±5 vs 59±2 %, $p<0.001$, and 60±5 vs 45±3 mm, $p<0.001$, respectively). The volumes of the four LV flow components differed between DCM and healthy subjects (in percentage of end-diastolic volume): *Direct Flow,* 20±1 vs 35±6%, $p<0.001$; *Retained Inflow,* 21±3 vs 17±4%, NS; *Delayed Ejection Flow,* 22±5 vs 15±3%, $p<0.01$, and *Residual Volume,* 36±6 vs 33±4%, NS (mean±SD). The *IVC distance* and the *IVC angle* were calculated for each trace of the LV volume at IVC (mean±SD, Figure 2). For both patients and healthy volunteers, *Direct Flow* and *Delayed Ejection Flow* are closest to the LVOT at the time of IVC. The directions of *Direct Flow* and especially *Delayed Ejection Flow* are oriented more directly towards the LVOT than the other, non-ejecting components of flow.

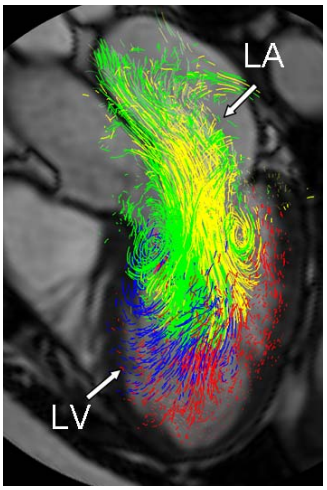

Figure 1. Pathline visualization of diastolic blood flow in a 51 year old healthy female. Semi-transparent 3-chamber image provides morphological orientation. LV = Left Ventricle, LA = Left Atrium. Pathlines color coded according to: Green, *Direct Flow*; Yellow, *Retained Inflow*; Blue, *Delayed Ejection Flow*; Red, *Residual Volume*.

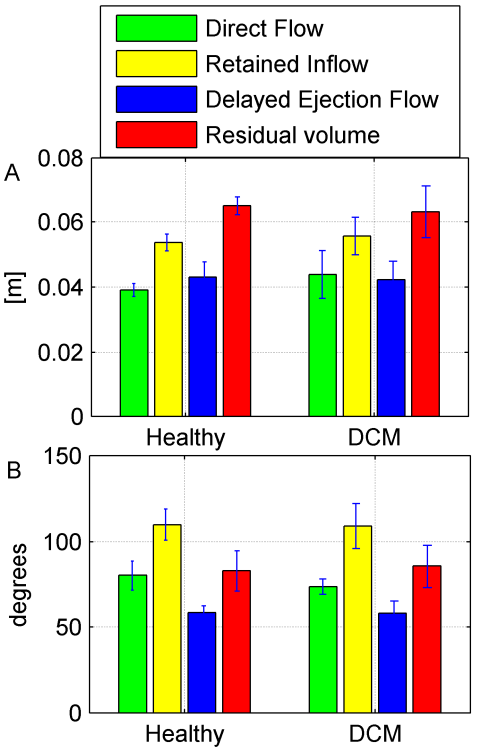

Figure 2. Mean *IVC distance* for each flow component (A). Mean *IVC angle* for each flow component (B). DCM = Dilated Cardiomyopathy.

Discussion: While the volumes of the four LV flow components showed significant differences between healthy subjects and DCM patients, no major differences could be seen in the position and the direction of the flow components at IVC between the two groups. The results indicate that by end diastole the positions and flow directions of *Direct Flow* and *Delayed Ejection Flow* are better oriented for their subsequent ejection from the LV than the *Retained Inflow* and the *Residual Volume* components. This may reflect an aspect of ventricular systolic efficiency that is impacted by flow-specific organization inside the diastolic ventricle.

References

[1] Eriksson J, et al. ISMRM workshop 2009, p47
[2] Dyverfeldt P, et al. JMRI 2008;28;655-63
[3] Bolger AF, et al. JCMR 2007;9;741-747