Validation of 4D Left Ventricular Blood Flow Assessment Using Pathlines

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Introduction: Multidimensional patterns of intracardiac blood flow remain poorly characterized in health and disease. We have previously presented a novel approach for the analysis of the 4D left ventricular (LV) blood flow patterns based on pathlines generated from three-directional, three-dimensional cine phase-contrast MRI (3DcinePC-MRI) data [1]. This pathlines method integrates morphological and flow data to separate the blood that transits the left ventricle into four components (Table 1) (figure 2) [2]. By definition, this permits an estimation of the total LV in- and outflow. As a validation of this method we compared the LV outflow obtained from this approach to results from clinically applied methods of determining LV outflow: 2D through-plane cine PC-MRI and Doppler ultrasound.

Materials and Methods: Nine subjects without left sided valvular regurgitation (six healthy subjects and three patients with dilated cardiomoypathy) underwent 3DcinePC-MRI during free-breathing, using a navigator gated gradient-echo pulse sequence [3] on a clinical 1.5 T scanner (Philips Achieva). Scanning parameters included VENC: 100 cm/s, TR/TE: 6.2/3.7 ms, voxel size: 3x3x3 mm^3, temporal resolution: 50 ms. Corrections were made for concomitant gradient-field effects, residual background phase errors and phase wraps. Pathlines were emitted from the LV volume at IVC and traced both backward and forward in time, and were used to compute LV inflow (*Pathline Inflow*) and outflow (*Pathline Outflow*) (figure 2), by multiplying the voxel volume with the number of traces entering and leaving the LV, respectively.
Doppler ultrasound data were collected in all nine subjects and LV outflow calculated according to the continuity equation (*US Doppler*). Two-dimensional through-plane cine PC-MRI data were acquired in a plane positioned approximately perpendicular to the ascending aorta just downstream of the aortic valve (VENC: 200 cm/s, TE/TR: 3/5 ms, slice thickness: 7 mm and pixel size: 1.6x1.6 mm^2). The outflow calculations from the 2D through-plane cine PC-MRI data (*2D Outflow*) was made by manually placing a region of interest in the data and integrating flow over time.

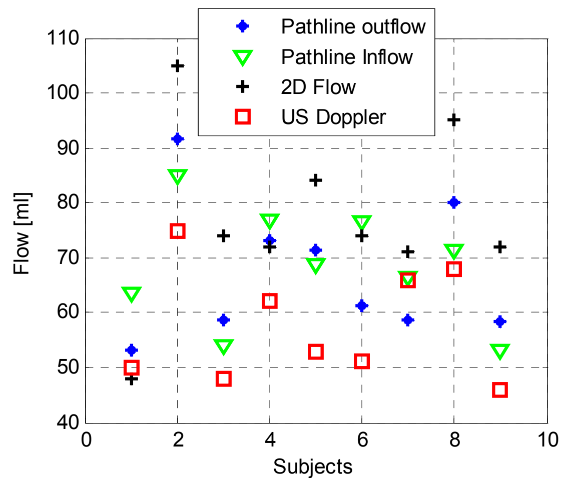

Figure 1. LV outflow volumes calculated from the pathline approach, 2D flow data and Doppler ultrasound, as well as inflow volumes from the pathline approach, n=9.

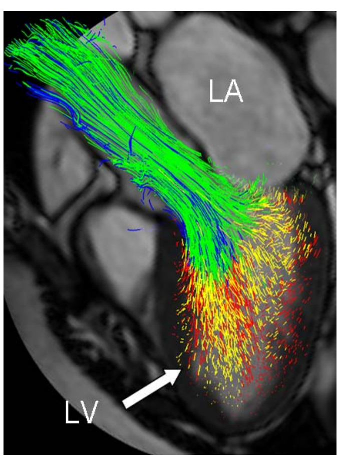

Figure 2. Pathline visualization of outflow in a healthy 51 year old female. Semitransparent 3-chamber image provides morphological orientation. LV=Left Ventricle, LA = Left Atrium. Pathlines colored according to: Green, Direct Flow; Yellow, Retained Inflow; Blue, Delayed Ejection Flow; Red, Residual Volume.

Results: A comparison between LV outflow obtained by the pathline approach, Doppler and 2D flow, as well as LV inflow obtained by the pathline approach, is shown in Figure 1.
The outflow calculated from the pathline approach (67±13ml), was significant larger than that from *US Doppler* (58±10 ml, p=0.006), and smaller than the *2D Outflow* volume (77±16 ml, p=0.001).
There was no significant difference between LV inflow (68±11 ml) and outflow obtained from the pathline approach (p=0.7).

Component	Definition
Direct Flow	Particles that enters and leaves the LV during the analyzed cc
Retained Inflow	Particles that enters the LV but does not leave during the analyzed cc
Delayed Ejection Flow	Particles that starts within the LV and leaves during systole of the analyzed cc
Residual Volume	Particles that resides within the LV for the entire analyzed cc

Table 1. Definitions of LV flow components. LV = Left Ventricle, cc = Cardiac cycle

Discussion: The pathline-based volumes appear to fall in between the LV outflow volumes obtained from the two other approaches. The difference between the volumes obtained from 2D through-plane and pathlines can be expected due to the differences in spatial and temporal resolution in the data acquisitions. The difference between the volumes obtained from Doppler ultrasound and the pathline approach is likely due to the assumptions made when calculating outflow from Doppler data (straight velocity profile and a circular outflow tract), as well as to the fact that these data are based on a one-directional velocity component.
The present pathline approach is not intended to replace LV outflow measurements with Doppler ultrasound or 2D through-plane PC-MRI. These findings suggest that the pathline flow assessment approach provides accurate LV volume estimations, in addition to providing valuable information on intraventricular 4D flow characteristics.

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