7D Flow through LVOT and aortic valve utilising k-t speed-up acquisition: initial work

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Introduction: Quantification of blood flow is an important tool in management of cardiac disease. Velocity encoding phase-contrast magnetic resonance (PC-MR) enables non-invasive quantification of blood flow in major vessels. Cardiac output, peak blood velocity and cardiac shunts measured using this technique have been shown to be accurate when compared to other clinical methods. However, due to long acquisition times, velocity mapping is only acquired in 2 spatial dimensions and one velocity encoding direction (in-plane or through plane) in the clinical setting. There have been some studies in which velocity mapping, in all 3 encoding directions, have been acquired in 3 spatial dimensions as a function of time (7 dimensional flow). Although they demonstrated the importance of complex flow patterns in maintaining optimum cardiac function, the long acquisition times precluded their use in the clinical environment. K-t acquisition technique [1] is a new method that considerably speeds up dynamic imaging. Applying the method to velocity mapping technique allows good spatial and temporal resolution in markedly less time than traditional methods. This allows velocity mapping in 3 spatial dimensions as a function of time in a single breath hold. Registration of consecutive volumes acquired using different velocity encoding directions gives 7 dimensional flow data. We demonstrate the feasibility of this technique in 1 volunteer.

Method: Each one of the three velocity-encoded volumes of the upper part of the heart (base, left ventricular outflow tract – LVOT, valve and beyond) was acquired in a single breath-hold with a cardiac-triggered, gated, k-t phase-contrast velocity imaging (T_1 FFE) on a 1.5 T Philips Intera (Philips Medical System B.V., The Netherlands). The total scan duration per volume was ~28s, TR ~4ms, TE ~1.4ms, with a spatial resolution of 1.3x1.3x5 mm^3 for 19 slices and 16 frames (heart rate ~53 bpm). For each velocity encoding direction, the V_{enc} was set to 100mm.s^{-1} in the right-left (RL) and anterior-posterior (AP) directions and 150mm.s^{-1} in the foot-head (FH) direction. Spurious phase errors were corrected before non-rigid volume-to-volume registration of the intensity (modulus) images. The RL and AP volumes were registered onto the FH volume, whose phase image carries the main direction of flow, to correct from interscan motion and respiration misalignment. The transformation matrices were then used to align the phase volumes. Thereafter, the three volumes were merged to generate a 3D vector field of the blood flow for each time frame. Initial points were defined on the lowest slice (see Fig.1), in the LVOT, from which pathlines were determined. The volume generation and pathline tracking were performed on IDL (© Research System, Inc).

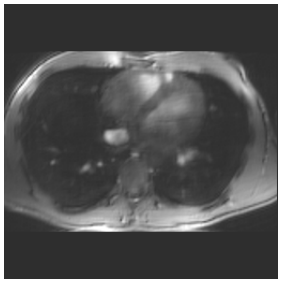

Figure 1 – Lowest slice corresponding to the LVOT.

Results: There was mild misalignment of the three volumes mainly due to variation in breath hold position. However, as the acquisition was performed at (end-) expiration, the largest differences between the registered and the initial volumes appeared on the anterior part of the heart. Thus there was minimal transformation following registration in our area of interest. We were able to follow pathlines of flow starting in the left ventricle through the aortic valve and into the ascending aorta for all the time phases. The pathlines appeared anatomically and physiologically appropriate. Example pathlines, shown in figure 2, were created from initial points in the anterior LVOT. We were able to visualize the acute change in the angle of flow as blood leaves the ventricle through the aortic valve. Changes over time of these pathlines also demonstrate the change in the geometry of the LVOT during systolic contraction. We found that if the starting points deviated from the mainstream flow, then the paths followed were no longer accurate.

Discussion: Our initial results show the advantages and potential use of 7D k-t flow. Not only was total scan time shorter, but additionally pathlines were followed anatomical structures when the initial points were well defined within the flow of blood. Most importantly, the experience demonstrated the applicability of the method in the analysis of flow pattern in the LVOT and through the valve over the cardiac cycle, independently of the motion of the heart during contraction. The necessity to set up the initial points well inside the flow to track the lines with accuracy is due to the spatio-temporal filtering of k-t method. This filtering could also reduce accuracy in cases of turbulences or highly accelerative flows. Misregistration could be further minimised with a respiratory navigator window during acquisition.

This technique could be applied to any part of the cardiovascular system and to patient populations especially with congenital heart disease and so help our understanding of the complex flow patterns seen in these patients and the importance of flow in their pathophysiology.

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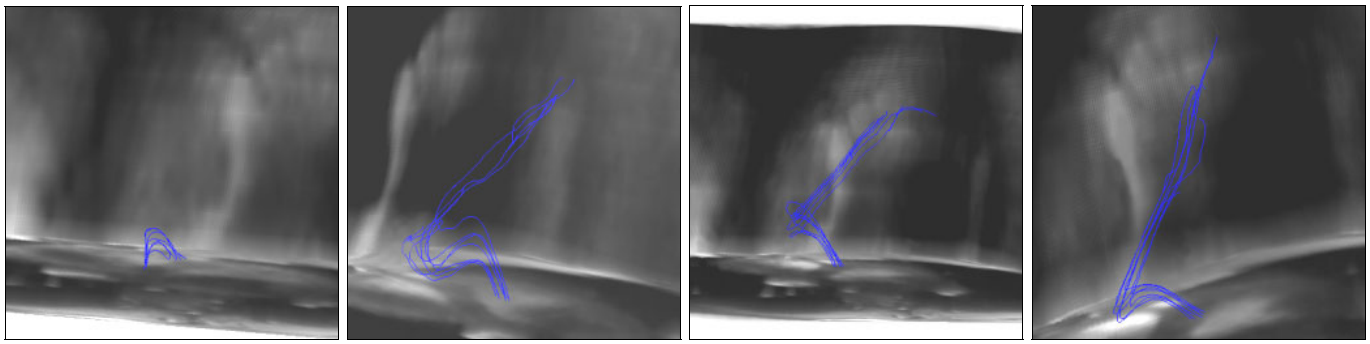

Figure 2 – Pathlines from the LVOT through the valve and to the aorta during systole. From left to right: a) pre-ejection, b-c-d) ejection. The projections are from different views to best demonstrate the direction of blood flow. The major observation is the acute bend, representing the valve, shifting down over contraction.

Reference:

[1] k-t BLAST and k-t SENSE: Dynamic MRI with high frame rate exploiting spatiotemporal correlations. J Tsao, P Boesiger, KP. Pruessmann - *MRM 2003, 50(5):1031 – 1042.*