4D flow of the Whole Heart and Great Vessels at 3T Using Real Time Self Respiratory Gating.

S. A. Uribe[1], P. Beerbaum[1], A. Rasmusson[2], T. Sangild Sørensen[3], R. Razavi[1], and T. Schaeffter[1]

[1]Division of imaging Sciences, Kings College London, London, London, United Kingdom, [2]Department of Computer Science, University of Aarhus, Aarhus, Denmark, [3]Centre for Advanced Visualisation and Interaction, University of Aarhus, Aarhus, Denmark

Introduction: Four Dimensional (4D) flow has been introduced as a means of acquiring anatomical and three-directional velocity information for pixels within a three dimensional volume over different time points [1]. The acquisition time for such data sets is extremely long and respiratory compensation is required. Navigator beams have been used in a study of blood flow hemodynamic of the entire aorta [2], however they could disturb the steady state and are time consuming. Indeed, to study the blood dynamic of the whole heart, flow information over the entire cardiac cycle is necessary. Self respiratory navigation can overcome these limitations. The use of a k_0 profile for self respiratory navigation has been recently demonstrated [3] for whole heart cine imaging and in phantom studies for phase contrast (PC) MR [4]. Here, we present an extension of this approach to acquire 4D flow data of an isotropic non angulated volume of the whole heart and great vessel in a free breathing scan. Results showed a strong correspondence between flow patterns obtained using this technique and with 2D phase contrast scans for different views of the heart. This approach represents an important advance for the characterization of the blood flow hemodynamics in the whole heart and a step forward to simplify cardiac MR examinations.

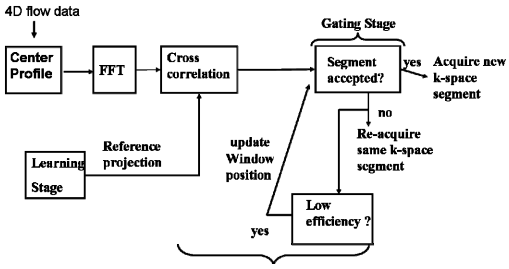

Figure 1. Block diagram of the algorithm to gate the 4D flow sequence in real time.

Materials and Methods*: Self navigation:* A 3D Fast Field Echo (FFE) PC sequence, with retrospective cardiac gating was used to acquire 4D flow data (Fig 1). The three flow directions and an anatomical image were obtained from a four flow hadamard encoded bipolar gradients [5], which were consecutively acquired to minimize motion artifacts in the phase-difference images. The sequence was modified to enable the acquisition of an extra k_0 profile for all four flows encodes at certain time intervals (e.g. every 70 ms) A specific coil element of a 6 cardiac coil channel was used to process k_0 profiles in a similar way as done in [3] (see fig 1). A fourier transform along the read out direction (Feet Head) yielded a projection of the whole volume. The breathing motion was obtained cross correlating the projections with a reference projection kernel in real time. This reference projection corresponded to an exhale respiratory position which was determined during the first 10 second of the scan. This respiratory signal was used to gate the sequence, i.e a windows of acceptance in millimeters determined whether the *k*-space data was accepted or rejected. If the efficiency of the scan was below 25%, the position of the acceptance windows was recalculated based on a histogram of the positions over the last 30 seconds (drift correction). ***Experiments:*** All the modifications were completely integrated into the software of a 3T Philips clinical scanner. A non angulated sagittal volume, 4D flow encoded, covering the whole heart and great vessels was acquired in 4 volunteers during a respiratory gated scan. The imaging parameters were 20-25 cardiac phases reconstructed form 15-18 acquired phases, resolution of 2.5x2.5x2.5, 25-30 slices interpolate 50-60, TR/TE = 4.1/2.1 and flip angle = 5°. For comparison, through-plane flows oriented at different views of the heart (transversal, coronal and in the Aorta (AO) and Pulmonary Artery (PA) just above the valves) were acquired (imaging parameters were: 25-30 cardiac phases reconstructed form 19-23 acquired phases, resolution of 2.2x2.2x 10 mm , TR/TE = 4.1/2.1 and flip angle = 15°). Quantification and visualization of the 4D flow were performed using a research software [5].

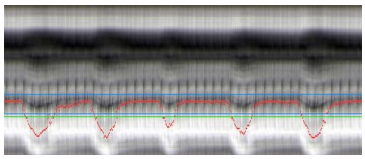

Figure 2: Real time display of k_0 projection along time. Blue lines represent the window of acceptance; red lines cross correlation signal, and green lines the size of the projection

Results: In all volunteers a reliable respiratory signal was obtained (see Fig 2). The efficiency of the scan was around 60-75% with a total scan time of 10-12 min for an acceptance windows of 8 mm. Reformatted slices of the entire aorta, Left ventricular output (LVOT) and pulmonary trunk during a systole phase are shown in figure 3, different colors represent the flow directions indicated by the arrows. Flow comparisons between the 2D flow and reformatted slices form the 4D flow are shown in figure 4 in different vessels of the heart. Notice the good agreement between the 2 techniques independent from the slice orientation.

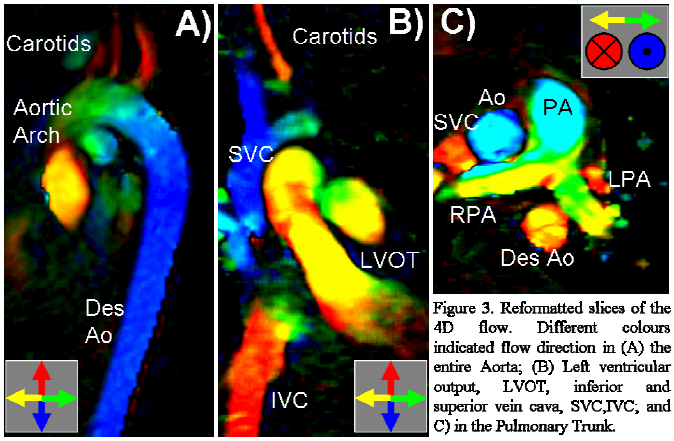

Figure 3. Reformatted slices of the 4D flow. Different colours indicated flow direction in (A) the entire Aorta; (B) Left ventricular output, LVOT, inferior and superior vein cava, SVC,IVC; and C) in the Pulmonary Trunk.

Conclusion: We have demonstrated the feasibility of 4D flow on the whole heart using a self respiratory gating technique. The method offers a series of advantages, since all flow characterization can be done form a single free breathing scan. A disadvantage of the technique is that the blood signal in the anatomical image decreases because of the lack of in-flow [6]. This method represents a practical advance for an easier cardiac MR examination. The technique would be very valuable in patients with acquired congenital heart disease, where 4D flow information of the whole heart could improve the diagnosis and treatment of such diseases.

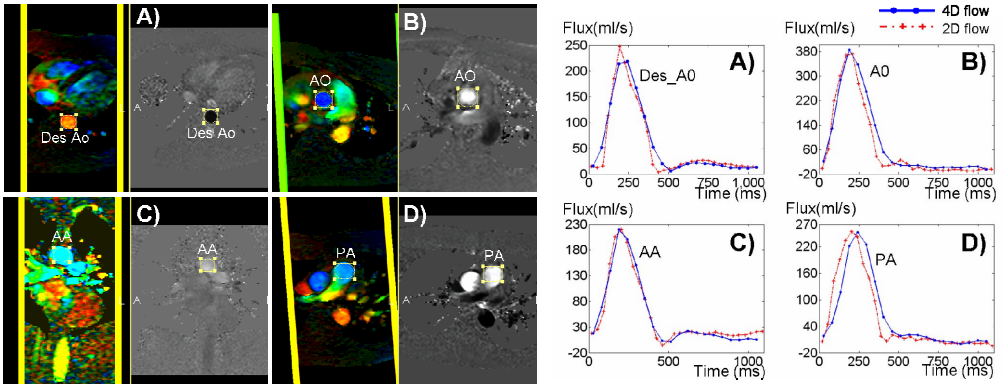

Figure 4. Flow comparison between 2D through-plane flow and 4D flow reformatted slices at the same view. The flow was measure in A) the descending aorta (Des Ao) form a transversal slice, B) in the Aorta (AO) just above the valves C) in the Aortic Arch (AA) from a coronal slice, and in D) in the Pulmonary Artery (PA). Good agreement between the 2D and 4D flow was found for the different orientations.

References: 1. Markl M et all, JMRI 2003; 2 Markl M et all, JMRI 2007; 3 Uribe et all, MRM 2007; 4) Van Ameron et all, ISMRM 2006; 5 Sorensen et all, Int J Cardiovasc Imaging; 6 Uribe et all, ISMRM 2007.