

4D flow of the Whole Heart and Great Vessels Using a Real Time Self Respiratory Gating Technique: A Validation Study.

S. A. Uribe Arancibia¹, P. Beerbaum¹, A. Rasmusson², T. Sorensen², R. Razavi¹, and T. Schaeffter¹

¹Division of Imaging Sciences, King's College London, London, United Kingdom, ²Department of Computer Science, University of Aarhus, Aarhus, Denmark

Introduction: Four Dimensional (4D) flow has been introduced as a means of acquiring three-directional velocity information over time for all pixels within a three dimensional volume [1,2]. In order to study the blood haemodynamic, the flow information over the entire cardiac cycle is necessary. The acquisition time of such data sets is extremely long requiring respiratory motion compensation. We have introduced a new self-gating technique for the acquisition of 4D flow data of an isotropic non-angulated volume [3]. In this study we validate this sequence in 15 volunteers by quantifying flow in different vessels and comparing it to clinically used 2D phase contrast technique. Furthermore the technique was applied to patients with congenital heart disease (CHD).

Method: A previously described sequence [4] that uses k_0 profiles for respiratory gating in real time was used to acquire 4D flow data of the whole heart and great vessels in 15 volunteers (resolution of 2.5mm³, 50-60 interpolated slices, 25 cardiac phases with 38 ms of temporal resolution, TR/TE = 4.1/2.1 [ms], flip angle = 6° and an acceptance window of 8 mm). To study the reproducibility of the technique, two 4D flow data sets were acquired with self-respiratory gating. To study the effect of respiratory gating an additional 4D flow data set was acquired without respiratory gating, but using two averages to ensure a similar overall scan-time. For comparison a number of 2D PC scans were obtained to quantify through-plane flow in the Aorta (AO), the main Pulmonary Artery (PA) and Left and Right PA) using a resolution of 2.2x2.2x 10 mm, TR/TE = 4.1/2.1, flip angle = 15° and 25 cardiac phases. Quantification and visualization of the 4D flow were performed using a research software tool [5]. Statistical analysis (T-test and Pearson's correlation) and Bland Altman plots were used to compare the stroke volume (SV) derived from the 4D and 2D flow acquisitions. Furthermore a 4D flow data set was obtained on a CHD patient with a repaired coarctation. The patient also has a levo atrial cardinal vein (LACV) that connects the left atrium with the innominate vein. Informed consent was obtained in all cases.

Results: The self-respiratory gated data acquisition was successful in all cases resulting in an overall scan time of 15±2.8 min. Table 1 shows the comparison of stroke volumes (SV) for the different techniques. Statistically difference was found for the SV in the LPA between the 4D non-gated data in comparison with the 2D technique. However, Bland Altman plots (Figure 1) for the different pairs of data sets showed a larger standard deviation and bias for the pair "4D non-gated vs 2D" in comparison with "4D gated vs 2D". Moreover, comparing the respiratory gating scans (4D gated t₁ and t₂) showed a negligible bias and a small standard deviation. Therefore, the respiratory gating of 4D acquisition resulted in significant higher accuracy in the flow quantification in comparison to the free breathing scan. Figure 2 shows the data obtained in the congenital patient. This data set was used to visualize the flow pattern in the region of coarctation. Furthermore, it allows the accurate quantification of the flux in the AO, PA, and in the LACV (Fig. 2 C) by reformatting the dataset in any arbitrary plane. We found the SV in the PA and AO was Q_p = 127.91 [ml] and Q_s = 90.68 [ml] respectively, which was equivalent of a cardiac shunt of Q_p/Q_s = 1.41. Indeed the SV measured by the 4D flow in the LACV was 38.06 [ml], which matches the difference of the SV between the PA and AO (Fig. 2 D).

Conclusion: We have validated a 4D flow technique that acquires data on the whole heart and great vessel using a self-respiratory gating technique. The method allows retrospectively flow quantification within the entire heart and great vessels from data obtained in a single free breathing scan. This method represents a practical advance for an easier cardiac MR examination and showed to be very valuable in patients with congenital heart diseases allowing retrospective analysis of flow in arbitrary planes and directions.

References. 1. Moran, MRI 1982. 2. Markl et al, JMRI 2003. 3. Uribe et al, ISMRM 2008. 4. Uribe et al, MRM 2007. 5.- Sorensen et al, IJCI 2005.

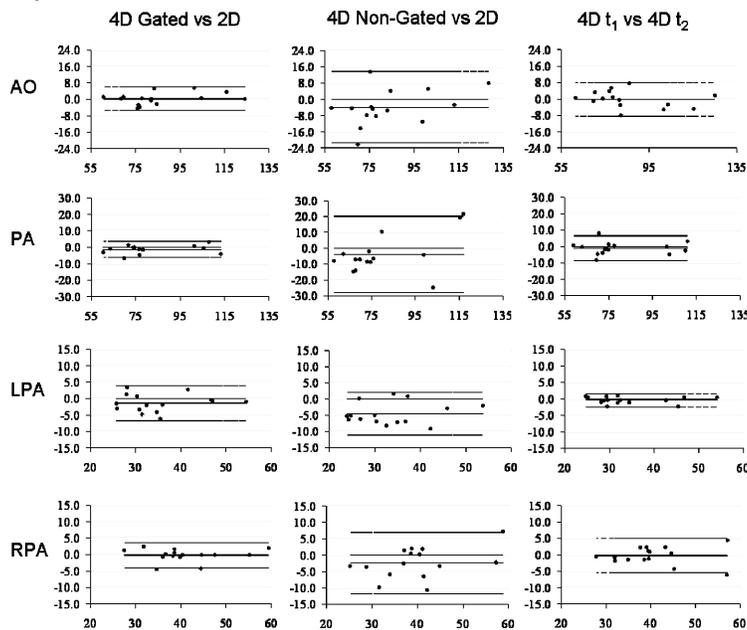


Figure 1. Bland Altman plots of Stroke Volumes of different vessels. Comparison between different acquisitions. 4D flow gated and non gated vs 2D flow. Last column is a comparison between two 4D flow gated scans, which show the reproducibility of the technique.

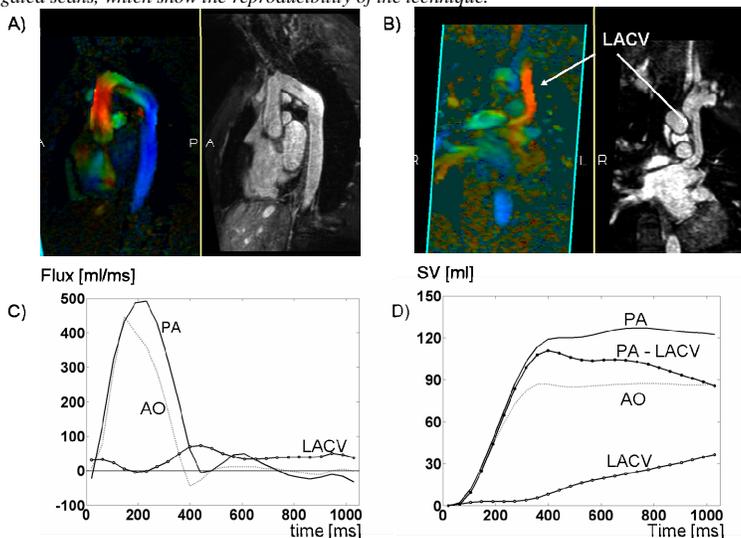


Figure 2. 4D flow data obtained in a CHD patient. A) shows a flow color encoded and anatomical image the repaired coarctation of the AO. B) Shows the flow in the Levo Atria Cardinal Vein (LACV) connecting the left atrium with the innominate vein. In C) and D) The flux and Stroke volume for the PA, AO, and LACV over the cardiac cycle are shown.

	4D gated t1	2D	4D non gated	4D gated t2
AO	85.86±18.54	85.65±17.54	81.78±21.03	85.62±17.37
PA	81.38±17.67	82.71±17.07	78.65±23.76	80.23±17.71
LPA	34.93±9.33	36.15±9.14	31.19±9.52	34.57±9.27
RPA	40.74±9.07	40.67±8.90	38.05±10.99	40.12±8.91