Evaluation of an optimized post-processing tool for 4D flow MRI data analysis in healthy volunteers and patients with aortic stenosis, aortic insufficiency, and aortic aneurysm

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Introduction: Evaluation for thoracic aortic aneurysm and aortic valve disease is a common indication for thoracic MR angiography and cardiac MR imaging. Traditionally, contrast-enhanced MR angiography, often supplemented by 2D phase-contrast imaging, is performed. However, emerging techniques such as 4D flow MRI, with ECG and navigator-gated data acquisitions with velocity encoding in all three spatial directions are poised to revolutionize clinical practice[1]. Beyond the long acquisition times, the principle barrier limiting the utility of 4D flow MRI in clinical practice is the post-processing time required [2]. Recently, a streamlined software tool has been developed specifically for analyzing thoracic aortic 4D flow MRI data, thus greatly shortening the required post-processing time [3, 4]. The purpose of this study was to evaluate the clinical utility of a novel post-processing tool for the routine clinical evaluation of thoracic aortic 4D flow MRI in patients with aortic aneurysm or aortic valve disease, and healthy controls. We aimed to determine the average 4D flow MRI dataset post-processing time and to compare regional flow quantificatyion at several positions along the thoracic aorta.

Methods: 4D flow MRI was performed at 1.5T or 3T (MAGNETOM Aera, Avanto, or Skyra, Siemens AG, Erlangen, Germany) in n=73 patients (52 men, 54±15 years) divided into four cohorts: healthy controls (n=19), thoracic aorta aneurysm (TAA. n=19), aortic valve (AoV) stenosis (AoVS, n=20) and AoV insufficiency (AoVI, n=15)(Table 1) using an in-house prototype sequence[1].Pre- and post-processing of the data was performed using prototype software(4D Flow Demonstrator V2.3, Siemens AG, Erlangen, Germany). 4D flow datasets were automatically corrected for background phase error due to eddy currents, velocity-aliasing, and motion. 3D segmentation of the thoracic aorta was performed by manually placing one seed point in the aortic root and one seed point in the distal descending aorta. A centerline and vessel model was then automatically calculated and used for vessel rendering, 3D blood flow visualization and flow quantification. Browsing along the centerline, four 2D analysis planes were placed in the thoracic aorta for flow analysis as shown in figure 1. For all planes, peak systolic velocity, net flow, and retrograde flow were quantified. In addition, 3D pathlines were created from seed points in the four planes to allow for 3D blood flow visualization (Figure 2). The time necessary to load a dataset into the program, to perform the quantitative analysis and to create the visualization movie for each subject was recorded. Comparison of velocity data between the study cohorts was performed using the student's t-test, $p<0.05$ was considered significant.

Results: 4D flow MRI analysis was successfully performed in all patients, and peak velocity, regurgitant flow, and net flow were calculated. 3D blood visualization of 3D blood flow with good quality, as exemplary illustrated in Figure 2 four cases from each cohort, was achieved in all cases. Total data analysis time was 9:42 minutes (range 5:01 to 31:24 minutes) and was longer in patients compared to healthy controls (Table 1). As shown in figure 3 the 4D Flow Demonstrator was able to detect statistical differences in peak velocities, net flow and retrograde flow consistently across groups (p<0,05).

Discussion: The 4D Flow Demonstrator enabled efficient processing of thoracic aortic 4D flow MRI datasets, allowing for 3D blood flow visualization and quantification of flow in a time frame appropriate for clinical utilization. Further studies are needed to validation the results compared to standard 2D PC-MRI and to assess observer variability. In summary, it was possible to fully process 4D Flow datasets in less than 10 minutes which points to the feasibility of 4D flow analysis in a clinical setting.

References:
1. Markl, M., et al., *4D flow MRI.* J Magn Reson Imaging, 2012. **36**(5): p. 1015-36. **2.** Hope, M.D., T. Sedlic, and P. Dyverfeldt, *Cardiothoracic magnetic resonance flow imaging.* J Thorac Imaging, 2013. **28**(4): p. 217-30. **3.** Gulsun M. et al., Proc. ISMRM 2012 #1176 **4.** Stalder A. et al., Proc. ISMRM2013 #1434

Cohort	Number of Subjects	Age	Gender	Total analysis time
Healthy controls	19	43±12	11 males	6:54 minutes
TAA	19	58±16	12 males	11:59minutes
AoVS	20	60±14	15 males	10:13 minutes
AoVI	15	54±15	14 males	8:42 minutes

Table 1: Subject demographics and average time for 4D flow MRI data analysis by cohort.

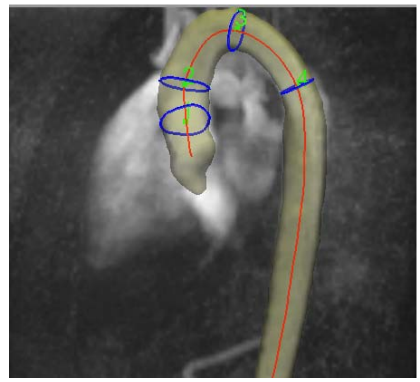

Figure 1: Graphical depiction of analysis plane positioning the thoracic aorta. (1)Distal to the aortic valve (AAo1), (2) mid ascending aorta (AAo2), (3) mid arch (Arch), and (4) descending aorta (Dao).

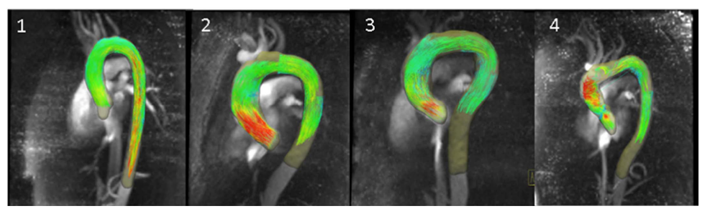

Figure 2: 3D streamlines for blood flow visualization at 4D flow MRI in representative datasets from (1) a healthy control, and patients with (2) thoracic aortic aneurysm, (3) aortic valve stenosis and (4) aortic valve insufficiency.

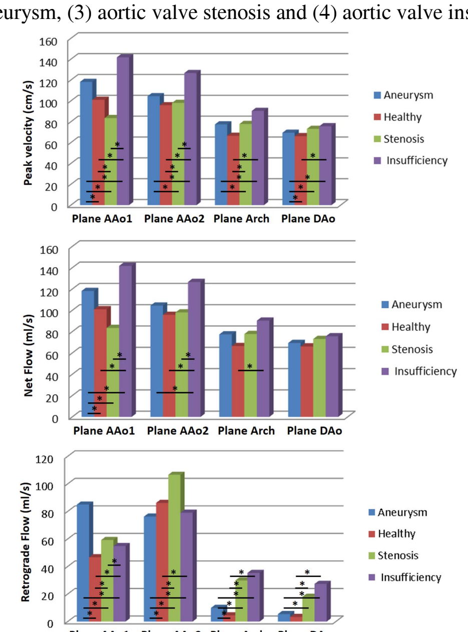

Figure 3: Average peak velocities, net flow and retrograde flow across planes 1-4 (see Figure 1) by cohort. Statistical differences between cohorts (p<0,05) are depicted by *.