

3D Blood flow Characteristic in the Left and Right Atrium in Patients with Atrial Fibrillation

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Introduction: Atrial fibrillation (AF) is a common cardiac arrhythmia associated with increased morbidity and mortality.¹ Patients with AF are at increased risk of systemic embolism (SE) and stroke, which can cause death, disability, and impaired quality of life.¹ It is known that AF is associated with an increased risk of thrombus formation within the left atrial (LA) cavity which is a major contributing factor to embolic stroke. Previous MRI and Doppler echocardiography studies have provided evidence that the increased risk of thrombus formation in the left atrium of AF patients may be related to flow abnormalities. In specific, decreased blood flow velocity (peak left atrial appendage velocities < 0.2m/s)² and thus increased stasis which is thought to promote blood clotting. Moreover, a recent 4D flow MRI study has shown that left atrial 3D hemodynamics was significantly different in patients with AF compared to healthy controls.³

Systematically reduced flow velocities (and thus increase residence times and stasis) may thus be an indicator of altered and low flow as a contributing factor to the underlying pathomechanism of thrombus formation. The purpose of this study was to employ whole heart 4D flow MRI with volumetric coverage of the the left and right heart for the evaluation of flow velocity distribution in both the LA and RA. Velocity histogram analysis was used to quantify differences in left and right atrial hemodynamics in patients in persistent AF, after successful treatment for AF (i.e. in sinus rhythm at the time of imaging) and compared to age matched healthy controls.

Methods: Whole heart 4D flow MRI data was performed in n=10 patients (age=67.9±8.0 years, 5 female) each with persistent AF, n=10 patients (age=61.5±10.5 years, 2 female) with AF but in sinus rhythm during the MR examination, and in n=8 age matched healthy volunteers (age=59.31±5.04 years, 3 female). All subjects underwent cardiac MRI on 1.5T MR systems (Siemens Avanto & Espree, Erlangen, Germany) under an IRB approved protocol. ECG and navigator gated free breathing 4D-Flow MRI was performed for each subject (velocity sensitivity = 100-150cm/s, spatial resolution = 2.5-3.0x2.5-3.0x3.0-3.5mm³, temporal resolution = 37.6-41.6 ms). After noise filtering, Maxwell, and eddy current correction, 3D PC-MR angiography (MRA) data or time-averaged magnitude (tMag) data was derived from the 4D flow data. As shown in figure 1, 3D-PC MRA or tMag data (depending on quality of atrial lumen contrast) were used for the 3D segmentation (MIMIC's Materialise 16.0, USA) of the left and right atrial geometry. For each subject, the 3D segmentation masks were then used to isolate the velocity data in the LA and RA volumes. The flow distribution for all atrial voxels and cardiac time frames were analyzed using velocity histograms normalized by the total number of entries to allow comparison across subjects. Mean, median and the relative number of voxels with velocities >0.2m/s (incidence) were calculated for each subject.

Results: 4D flow MRI was successfully performed and analyzed in all n=28 subjects including 3D segmentation of the LA and RA and calculation of normalized velocity histograms. Consistent with previous studies^{2,3}, LA mean and median velocities as well as incidence were reduced in AF patients compared to controls while patients in AF demonstrated the most significant reductions (figure 2 and table 1). A highly similar trend was found for the RA as evident from histogram shapes in figures A to C which demonstrated similar changes in cohort averaged velocity distributions for the RA and LA (more skewed toward low velocities for AF patients). For both RA and LA, all velocity parameters in patients in persistent AF were significantly reduced compared to age matched controls ($p<0.05$, table 1) indicating disturbed flow and increased stasis. In addition, persistent AF resulted in lower LA and RA velocity parameters compared to AF patients in sinus which was significant for RA median velocity (table 1). A trend towards higher velocities in the RA compared to the LA was observed for controls and AF patients in sinus (table 1). However, differences in RA vs. LA flow were not significantly different and varied considerably between individuals (figure 2 D,E).

Discussion: 4D flow MRI demonstrated that persistent AF resulted in different blood flow velocity distribution compared to AF patients in sinus and normal controls for both the RA and LA. Differences between LA and RA hemodynamics were less pronounced than expected but showed a trend towards increased incidence of higher RA velocities which may explain reduced rates of pulmonary versus systemic embolization. Due to the high inter-individual variability of LA versus RA, further studies with larger patient cohorts are warranted to better understand differences in RA and LA flow and their relationship to other demographic and risk factors.

Acknowledgements: Grant support by AHA grant-in-aid 12GRNT12080032; NIH R21 HL113895.

References: 1. Roger VL, Circulation. 2012 Jan 3;125 (1):e2-e220. 2 Bernhardt P, JACC 2005;45(11):1807-1812. 3. 1. Fluckiger JU, J Magn Reson Imaging 2013.

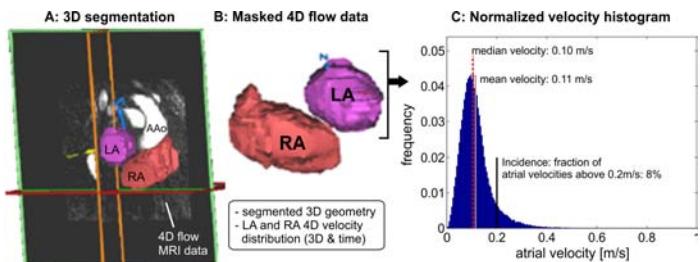


Figure 1: The left atrium is illustrated in pink while the right atrium is illustrated in red on a 76 year old male with treated AF.

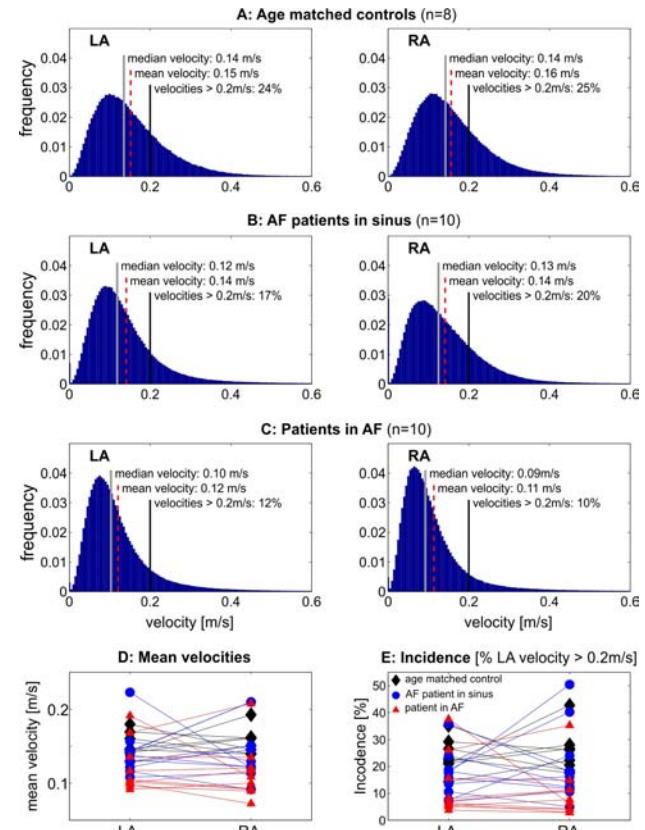


Figure 2: Left (LA) and right (RA) atrial velocity distributions (cohort averaged velocity histograms) in age matched controls (A), post-treatment AF patients in sinus rhythm (B), and patients in persistent AF during 4D flow MRI (C). D, E: Hemodynamic differences (mean velocity and incidence) between the LA and RA for all the cohorts.

	mean velocity [m/s]		median velocity [m/s]		incidence [% > 0.2m/s]	
	LA	RA	LA	RA	LA	RA
controls	0.15 ± 0.02	0.16 ± 0.02	0.14 ± 0.02	0.14 ± 0.02	24.0 ± 6.3	25.3 ± 8.0
AF pts in sinus	0.14 ± 0.03	0.14 ± 0.04	0.12 ± 0.02	0.13 ± 0.02 * </td <td>16.9 ± 8.5</td> <td>20.3 ± 14.3</td>	16.9 ± 8.5	20.3 ± 14.3
patients in AF	0.12 ± 0.03 #	0.151 ± 0.04 #	0.10 ± 0.03 #	0.09 ± 0.02 #	12.0 ± 11.2 #	11.3 ± 9.7 #

Table 1: Descriptive statistics of left (LA) and right (RA) atrial velocity distributions for all three cohorts.

significant difference between patients in AF and controls ($p<0.05$)