

## Age-Related Differences of 3D Blood Flow in the Left Heart

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**Introduction:** Alteration of blood flow could carry enormous consequences in valvular heart diseases, in left ventricular (LV) remodeling of the ischemic heart, or in the development of aortic diseases. Assessing blood flow might thus improve therapies such as valvular or aortic surgical interventions. However, a comprehensive analysis of intra-cardiac flow patterns is often not performed and only limited data on normal atrial and ventricular flow patterns and their changes during aging are available. In this study, we used a flow-sensitive MRI technique with volumetric 3D coverage of the whole heart and 3-directional velocity encoding to visualize the complex 3D blood flow within the left atrium and LV. As aging alters LV function, our aim was to provide a detailed analysis of the properties and age dependent differences in normal 3D intra-cardiac blood flow.

**Methods:** All examinations were performed on a 3T MR system (Trio, Siemens, Erlangen, Germany) using a standard 12-element torso coil. We examined 23 healthy volunteers in two age groups: <30 years (n=11, age 23.3±1.5 years, 6 women) and >50 years (n=12, age 58.4±4.1 years, 6 women). Data acquisition consisted of a k-space segmented rf-spoiled gradient echo sequence with interleaved 3-directional velocity encoding (spatial resolution = 2.5x2.5x2.8mm<sup>3</sup>, temporal resolution = 38.4ms, scan time ~ 15-25min), prospective ECG-gating and adaptive diaphragm navigator gating (1).

To assess the complex data, 3D flow visualization was employed (EnSight, CEI, USA). We analyzed 3D particle traces originating from emitter planes in the pulmonary veins demonstrating time-resolved blood flow. Furthermore, vector fields were calculated for each time point. To improve anatomic orientation vector fields were fused with 2D CINE SSFP images in 2- and 4-chamber views. To identify and grade intra-atrial and intra-ventricular vortex flow, particle traces and vector graphs were analyzed semi-quantitatively as follows:

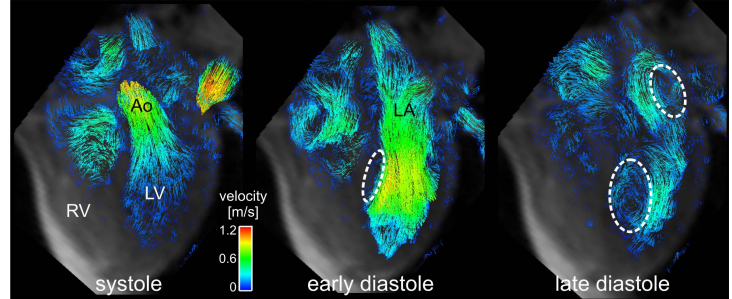
- Left atrium (LA): Number and degree (4-point scale) of systolic and diastolic vortices: 1 = not existent, 2 = mild, 3 = moderate, 4 = pronounced based on particle traces originating in each of the 4 pulmonary veins
- LV (2-chamber and 4-chamber view) and LA: Peak diastolic LV in-flow velocity and systolic and diastolic vortex formation (number, degree, duration, extent, and peak velocity inside the vortex) at base, mid, and apex.

**Results:** Vortex formation in the LA was more pronounced for younger individuals (tab. 1) without reaching significance. Vortices were more prominent in blood flow originated from left than from right pulmonary veins. Peak LV diastolic in-flow velocity was significantly higher in younger volunteers (93±14cm/s vs. 78±18cm/s in the older subjects, p=0.04). The highest incidence, extent, and peak velocities of vortex flow were found in basal parts of the LV for both age-groups. However, vortices within the basal LV were more pronounced and their peak velocities were significantly higher in the younger volunteers (see fig. 1, tab. 2). In the mid-LV, younger individuals demonstrated more vortices than older volunteers. In young subjects, the duration of vortices was longest in the mid-LV. In both age-groups the vortices in the apex were smaller with shorter duration and lower velocities. The number of systolic LA vortices ranged from 1-4 (< 30 years) and 0-5 (>50 years) and in diastole from 0-3 for both age-groups. However, diastolic LA vortices were less prominent in older volunteers (6 subjects showed no vortex compared to 2 <30 years). Most subjects revealed 2 vortices in the LV base irrespective of age, whereas in the midventricular LV most young volunteers had 2 and most old subjects only 1 vortex.

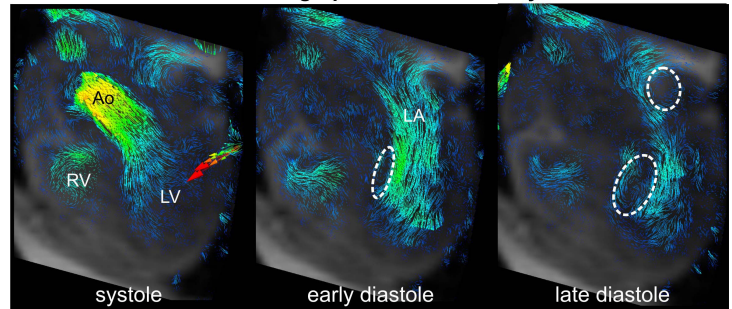
**Discussion:** Flow-sensitive 4D MRI with whole heart coverage revealed significant age-related differences in intra-atrial and intra-ventricular flow patterns. In earlier studies with vector particle image velocimetry, altered LV vortices were described in patients with systolic LV dysfunction (2). The older individuals of our cohort revealed a tendency towards a lower degree and number of diastolic LV vortices despite normal ejection fraction. This finding might reflect the onset of age-related diastolic dysfunction or changes in LV geometry in these individuals. The differences are not explained by heart rate, which did not differ between age-groups (65.5±9/min vs. 67.3±6.4/min). Although the number and extent of the LV vortices differed individually, most volunteers of our cohort revealed vortical flow not only in the basal parts of the LV, but also in midventricular or even in apical segments. Only one individual (older age-group) presented with only 2 vortices in the base as described previously (3). The findings of this study indicate the importance of age matched control groups when pathological flow changes are investigated.

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### A: 4-chamber view & vector graphs volunteer < 30 years



### B: 4-chamber view & vector graphs volunteer > 50 years



**Fig. 1:** Vector graph visualization of intra-cardiac blood flow in a young (A) and old (B) normal volunteers. The formation of diastolic vortex flow in the left atrium (LA) and left ventricle (LV) is clearly evident and indicated by the dashed circles. Note the reduced diastolic in-flow velocities (color coding) and less pronounced vortex flow in the older volunteer. RV: right ventricle, Ao: aorta.

| Vortices LA     | Number  | Degree  | Duration(ms) | Extent(mm <sup>2</sup> ) | Vmax(cm/s) |
|-----------------|---------|---------|--------------|--------------------------|------------|
| <b>Systole</b>  |         |         |              |                          |            |
| <30y (n=11)     | 1.9±0.9 | 2.3±0.7 | 174±68       | 350±279                  | 41±11      |
| >50y (n=12)     | 2.0±1.2 | 1.9±0.9 | 169±112      | 256±167                  | 36±12      |
| <b>Diastole</b> |         |         |              |                          |            |
| <30y (n=11)     | 1.7±1.0 | 2.1±0.8 | 111±5        | 219±194                  | 37±8       |
| >50y (n=12)     | 1.0±1.2 | 1.6±0.6 | 70±50        | 157±100                  | 27±11      |

**Tab.1:** Cumulative results of vortex analysis in the left atrium (LA) for the young (<30y) and the older age-group (>50y). Data represent mean values±standard deviation, Abbreviations: Vmax: peak velocity

| Vortices LV | Number   | Degree   | Duration(ms) | Extent(mm <sup>2</sup> ) | Vmax(cm/s) |
|-------------|----------|----------|--------------|--------------------------|------------|
| <b>Base</b> |          |          |              |                          |            |
| <30y (n=11) | 1.8±0.4  | 2.9±0.3  | 126±37       | 473±201                  | 65±9       |
| >50y (n=12) | 1.9±0.3  | 2.4±0.6* | 131±55       | 438±155                  | 52±10*     |
| <b>Mid</b>  |          |          |              |                          |            |
| <30y (n=11) | 1.7±0.7  | 2.5±0.6  | 155±103      | 452±333                  | 54±19      |
| >50y (n=12) | 1.1±0.7* | 2.3±0.9  | 130±89       | 381±212                  | 43±14      |
| <b>Apex</b> |          |          |              |                          |            |
| <30y (n=11) | 0.5±0.7  | 1.6±0.5  | 72±33        | 152±51                   | 26±6       |
| >50y (n=12) | 0.5±0.7  | 1.8±0.8  | 84±50        | 124±55                   | 28±8       |

**Tab.2:** Cumulative results of vortex analysis in the left ventricle (LV) for the young (<30y) and the older age-group (>50y). Data represent mean values±standard deviation, \* represent significant differences between both age-groups (p<0.05)