Evaluation of 3D Blood Flow Changes in the Normal and Dilated Thoracic Aorta using flow-sensitive 4D MRI.

J. Bürk[1], Z. Stankovic[1], A. Frydrychowicz[1], M. Langer[1], and M. Markl[1]
[1]Department of Diagnostic Radiology, Medical Physics, University Hospital Freiburg, Freiburg, Germany

Introduction: Sixty percent of thoracic aortic aneurysms involve the ascending aorta (AAo) [1]. A severe consequence of aneurysms is aortic dissection or rupture, which is often lethal. Therefore, for most AAo aneurysms, surgery is indicated at a diameter of 5.5 cm. Although it is known that the mean rate of growth for thoracic aneurysms is 0.1 cm/y [2], there is substantial variation in individual aneurysm progression and it is still not possible to prospectively and reliably predict growth of a given aneurysm [3]. In this context, the assessment of aortic hemodynamics and the presence of altered flow patterns and thus wall shear forces associated with changes in shape and size of the aorta may provide further insights in aneurysm development. Time-resolved 3D phase contrast MRI with 3-directional velocity encoding (flow-sensitive 4D MRI), which was previously applied e.g. for the evaluation of supraaortic arteries or the left heart [4,5] can provide comprehensive information on aortic hemodynamics. It was the purpose of this study to identify 3D flow pattern changes in the thoracic aorta in correlation to the vessel geometry in a study with 63 subjects (AAo diameter ranging from 2.5cm-5.1cm).

Methods: Aortic hemodynamics were assessed in a study with n=63 subjects. Aneurysm patients (n=33, 3 female, age 60±16years) had a dilated or aneurismal AAo ≥4mm. For comparison, 15 healthy young volunteers (3 female, age 23±2years) and 15 age matched normal controls (3 female, age 67±8years) were also included. All examinations were performed on a 3T MR System (Siemens, Erlangen, Germany) using flow-sensitive 4D MRI based on an RF-spoiled gradient-echo sequence with interleaved three-directional velocity encoding. All measurements were prospectively gated to the ECG cycle and performed during free breathing using navigator respiratory gating. Data were acquired in a sagittal oblique 3D slab encompassing the aorta (venc =150m/s, α=7-15°, TE=2.7-3.5ms, TR = 5.1-6.1ms spatial res. = 1.6-2.2 x 2.1-2.5 x 2.4-3.0mm^3, temporal res. = 40.8-48.8ms). Data processing included eddy and velocity aliasing correction and the calculation of a 3D phase contrast angiogram (figure 1, gray shaded iso-surfaces). Flow pattern analysis (EnSight, CEI, Apex, USA) was based on time-resolved particle traces originating from manually positioned emitter planes in AAo, arch, and descending aorta (DAo). As illustrated in fig. 1, helix and vortex flow were defined as regional circular flow patterns deviating by more than 180° from the physiological flow direction. Helicity was considered an overall corkscrew-like motion of blood along the direction of flow (figure 1B), whereas vortices resembled recirculating areas within the vessel (figure 1A). Helix and vortex severity were graded in the AAo, aortic arch, and DAo by two independent observers in 3 categories: none = 0, moderate helix/vortex (flow rotation <360°) = 1, pronounced helix/vortex (flow rotation >360°) = 2. For helix flow, the direction of flow ration was recorded. It was also recorded if the vortex partly or fully filled the aortic lumen.

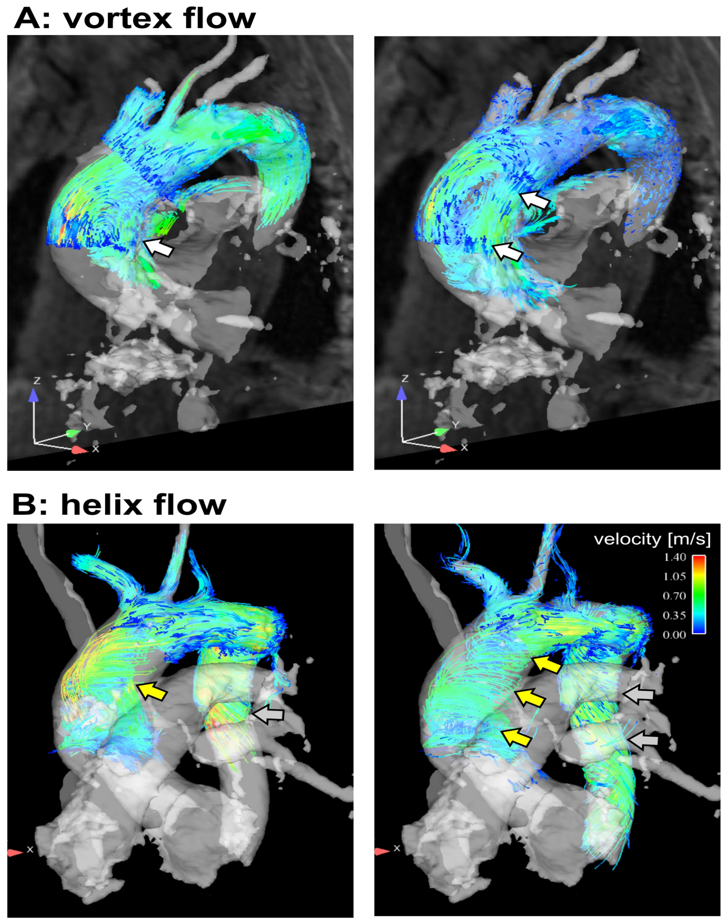

Fig.1: Early (left) and late (right) systolic time-resolved particle traces show the formation of a large flow vortex encompassing the entire AAo (A, white arrows, grading = 1.5, AAo diameter = 40mm). B: Helix flow (B, yellow arrows, grading = 2) in the ascending (diameter = 48mm) and descending aorta (B, grey arrows).

Results: In aneurysm patients, diameters of the AAo (44mm±4mm) and AAo/DAo diameter ratio (1.6±0.3) were significantly ($p<0.05$) increased compared to age matched controls (35mm±2mm, 1.3±0.1) and healthy volunteers (27mm±2mm, 1.3±0.2)**.** A significantly enhanced incidence and strength ($p<0.05$) of helix flow in the AAo was observed in n=16 patients (48%, grading 0.9±1.0) compared to n=2 age matched controls (13%, grading 0.2±0.6) and n=1 young healthy volunteers (7%, grading 0.1±0.3). Vortex flow was present in the ascending aorta in almost all of aneurysm patients (n=31, 94%), in half (n=7, 47%) of the age matched controls and was completely absent in young healthy volunteers. Vortex flow was more pronounced in aneurysm patients with a grading of 1.5±0.6 compared to 0.6±0.7 in the age matched control group ($p<0.05$) and filled the entire aortic lumen in 58 % of cases compared to 10% in age matched controls. Helix and vortex flow was observed less frequent (7-15%) in the aortic arch and descending aorta in all groups. If existent, helix flow was right-handed in all but one case. The existence and increased strengths (grading) of ascending aortic helix and vortex flow was directly associated with an increase in AAo diameter and AAo/DAo diameter ratio (fig. 2).

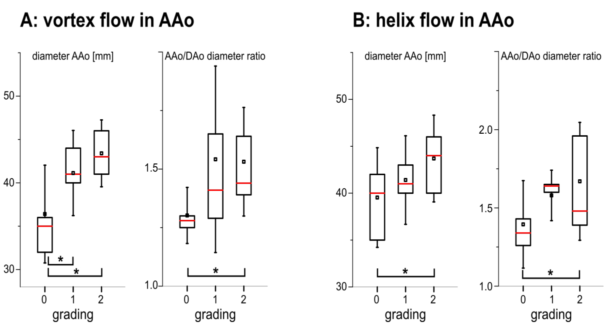

Fig. 2: Differences in aortic geometry for all aneurysm patients und age matched control (n = 48). * indicates significant differences.

Discussion: The results of this study demonstrate that flow-sensitive 4D MRI is able to visualize geometry dependent flow pattern alterations in the thoracic aorta. The study shows that there is a significant relationship between vesssel diameter in the AAo, AAo/DAo diameter ratio and the incidence and strength of irregular blood flow. As mentioned above it is currently not possible to prospectively predict the growth rate or the critical diameter of a given aortic aneurysm [3]. On the one hand the risk of rupture rises up abruptly as aneurysms of the AAo reach a size of 6.0 cm, on the other hand the annual rupture rate of aneurysms smaller 5.0 cm is at least 2% [2]. Based on the high risk of often lethal rupture of ascending aneurysm a precise prediction about the growth rate and the probability of rupture would be important. This study presents a first investigation of blood flow alterations in a large cohort of patients with dilated or aneurismal aortic shape compared to age matched and younger control groups. Longitudinal follow up studies are now needed to correlate growth rate or high rupture risk even of samller aneurysms with the stength of vortex and helix flow. Such follow-up studies should observe the process of the aneurysms in the patient group to investigate possible correlations between aneurysm growth rate/risk of rupture and blood flow alterations. Since it is expected that helix and vortex flow will lead to regionally altered vessel wall shear stress, it is important to examine quantitative changes in blood flow and vessel wall, e.g. segmental wall shear stress, in future studies.

Acknowledgements: Deutsche Forschungsgemeinschaft (DFG), Grant # MA 2383/5-1, Bundesministerium für Bildung und Forschung (BMBF), Grant # 01EV0706.

1. Isselbacher EM.Circulation. 2005 Feb 15;111(6):816-28. **2.** Davies RR et al.. Ann Thorac Surg. 2002;73:17–28. **3.** Dapunt OE et al.. J Thorac Cardiovasc Surg. 1994;107:1323–1332. **4.** Frydrychowicz A et al..J Comput Assist Tomogr. 2007; 31:9-15. **5.** Frydrychowicz A, et al.. Magn Reson Imaging, 2007; 25:1085-92.