Initial results from diameter dependence of thoracic aortic hemodynamics acquired by 4D flow-sensitive MRI at 3T.

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Introduction: Large efforts to characterize blood flow characteristics in the aorta and to correlate those with the presence of atherosclerosis have been made using 2D MR measurements [1] and CFD simulations [2]. Initial results by 3D velocity mapping were presented in the late 90s [3]. More recently, ECG and respiration controlled time-resolved 3D phase contrast MRI with 3-directional velocity sensitivity (flow-sensitive 4D MRI) was applied to the entire 3D geometry of the aorta for detailed visualization and semi-quanititative analysis of the true 3D blood-flow characteristics at 1.5 [4] and 3T [5,6]. In light of diseases such as Marfan's syndrome, idiopathic aneurysms and the formation of aneurysms as a complication (i.e., in coarctation) the aim of this study was to analyze the diameter dependence of aortic hemodynamics with respect to characteristic blood flow patterns such as location-specific maximum velocities, presence of helical or vortical flow, retrograde flow and helicity indicate that the size can considerably influence hemodynamic properties of the thoracic aorta which can be correlated to a later analysis of wall shear stress (WSS) and oscillatory shear index (OSI).

Methods: Experiments were performed on a 3T MR-system (TRIO, Siemens, Germany) after written informed consent of all 16 volunteers and 13 patients. 3D blood flow measurements covering the entire thoracic aorta were performed applying flow sensitive 4D-MRI using an eight channel body coil and an rf-spoiled gradient echo sequence with interleaved 3-directional velocity encoding (BW = ± 480 Hz/pixel, flip angle=15°, TE / TR=3.67 / 48.8 ms, venc = 1.5 m/s, spatial resolution =(2.71 - 2.93 x 1.58 - 1.69 x 2.60 - 3.0) mm³, temporal resolution = 48.8 ms). The measurement was prospectively gated to the ECG cycle and utilized a previously reported adaptive navigator technique [5] to enable free patient breathing during the acquisition.

Data analysis: Semi-quantitiative data analysis was performed in 8 indiviuals with small aortic diameter (SAD group) and 7 with an aortic diameter larger than 3.5cm (LAD group). Nine 2D planes according to the schematic drawing in Fig. 1 were interactively positioned orthogonal to the vessel lumen. Local vascular hemodynamics was visually graded using time-resolved vector fields and color-coded velocity shading mapped onto the individual planes. Data evaluation for each 2D plane included localisation of maximum blood flow velocity, maximum systolic inplane rotation, and maximum systolic retrograde flow within luminal quadrants as illustrated in figure 1, right. Also, the presence and localization of flow vortices was reported and time-to-peak systolic velocity, max time of in-plane rotation, and maximum duration of retrograde flow was recorded for each slice. Based on 3D stream-line visualization (fig. 1, left) systolic aortic flow helicity was determined. Further, the angle of the aortic arch, diameters of the aorta at 3 locations and the flow profile were recorded.

Results: For most results please see the comparison of results in figures 2-4. The SAD group showed diameters of 2.4±0.3cm, the LAD group diameters of 3.9±0.6 cm. Only non-laminar flow was seen. Vortices were seen in the LAD group and usually larger than the local aortic diameter and predominantly retrograde. Only if located in the arch or DAo vortices were smaller and sometimes antegrade.

Discussion: The result of this study indicate the potential of flow sensitive 4D MRI for the identification of diameter dependent aortic flow patterns. By semi-quantitative analysis of aortic hemodynamics we were able to show in a small cohort of individuals that the size of the aorta influences the hemodynamic properties. This implicates changes of the wall shear stress and oscillatory shear index which has a known influence on arterial remodelling and artherogenesis. A larger sample size will have to reveal whether significant differences in aortic blood flow patterns can be found comparing individual diameters and clarify whether these characteristics will have an impact on diagnostic an therapeutic decision-making.

References: [1] Wentzel JJ, JACC. 2005;45:846-54; [2] Steinman DA, Ann Biomed Eng. 2005;33:1704-9; [3] Bogren HG, J Magn Reson Imaging. 1999;10:861-9; [4] Markl M, J Comput Assist Tomogr. 2004;28:459-68; [5] Markl M, J Magn Reson Imaging 2006, in press; [6] Frydrychowicz A, Circulation. 2006;113:e460-1

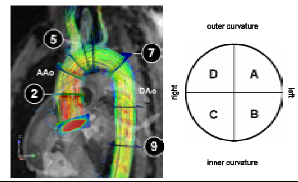

Fig. 1: Localization of 9 cutplanes (0-8) in the aorta and orientation of quadrants for analysis of maximum flow velocity, retrograde flow and inplane rotation in every slice. AAo = ascending aorta, DAo = descending aorta.

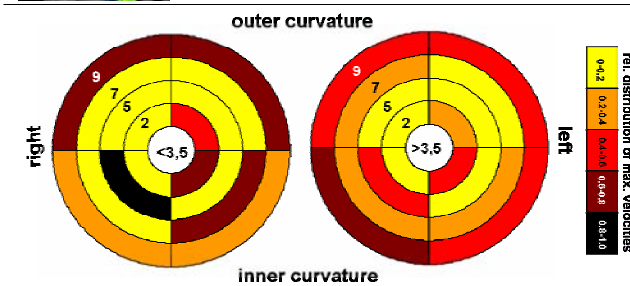

Fig. 2:
Exemplary display of the max. velocity localization in the quadrants of cutplanes 2, 5, 7, and 9 in SAD individuals (right) and LAD (left). The main difference between SAD and LAD group is the greater heterogeneity in the LAD group whereas in both maximal flow is located at the inner curvature of the AAo and the aortic arch and the outer curvature of the DAo.

Fig. 3:

AAo diameter	<3.5cm diameter	>3.5cm diameter
Helicity	R-handed, prominent	poor, sometimes L-handed
Vortices	None, except one	Always, 2-5
Retrograde Flow	moderate, arch and DAo	prominent, AAo, Dao and aortic arch
Inplane rotation	moderate	prominent

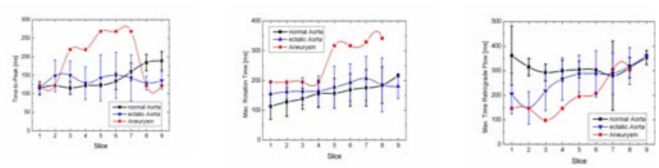

Fig. 4: Time to peak (TTP) systolic flow (left), time point of max. systolic inplane rotation (middle), and time of max. retrograde flow occurrence for all cutplanes. No overt differences can be distinguished between normal and ectatic aortae for TTP and inplane rotation. In the patient however, TTP is markedly decreased and inplane rotation increased.

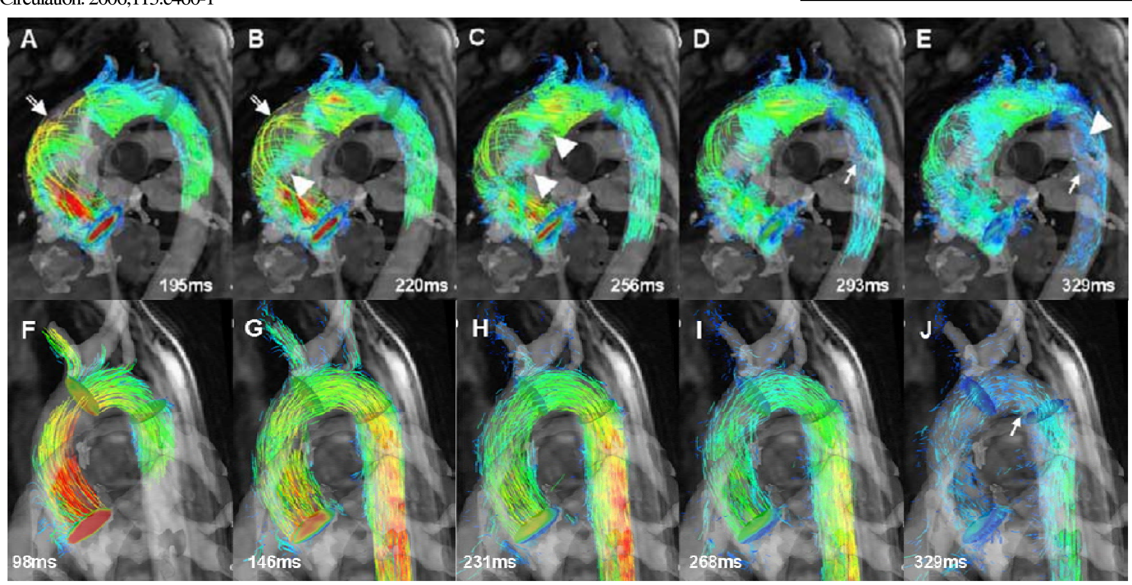

Fig 5: A-E: Hemodynamic alterations in a patient with an ascending aortic aneurysm (diameter 5,2 cm) and F-J: a volunteer from the SAD group with unsuspicious hemodynamic patterns and an ascending aortic diameter of 2,4 cm. Clearly, multiple vortex evolutions (white arrowheads) and the more prominent retrograde flow (white arrows) can be appreciated. Also, the large inplane rotational component can be understood if the large helicity in the ascending aorta (open white arrow) and the vortices are taken into account.