Time-Resolved 3D MR Flow Analysis at 3T: Insights into Major Hemodynamic Changes Associated with Aortic Pathologies

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Introduction: The knowledge of local vascular anatomy and function in the human body is of high interest for the understanding, diagnosis and treatment of disease.
In this study, blood flow characteristics associated with common aortic pathologies and the effect of surgical intervention were analyzed using ECG synchronized and respiration controlled 3-dimensional MR velocity mapping at 3 Tesla (3T) and advanced 3D visualization. The comparison of results from volunteers and patients illustrates that even small pathological geometric changes such as mild aneurysms or prosthesis repair bear a major impact on local vascular hemodynamics and can severely alter blood flow characteristics [1,2].

Methods: 4 healthy volunteers and 9 patients with aortic pathologies (aortic and abdominal aneurysms, luminal narrowing in the aortic arch and subclavian artery and Ductus Arteriosus Botalli) and surgical repair (Dacron prosthesis repair after Typ A dissection and traumatic aortic rupture) were investigated in this study.
All examinations were performed on a 3T MR system (TRIO, Siemens, Germany) using time-resolved 3D MR velocity mapping (rf-spoiled gradient echo sequence) with interleaved 3-directional velocity encoding (venc =150cm/s). Data were acquired in a sagital oblique 3D volume that included the entire thoracic aorta (spatial resolution (1.6-2.1x2.4-4.0x3.5-5)mm^3). Measurements were synchronized with the cardiac cycle using prospective ECG gating in combination with k-space segmented data acquisition resulting in a CINE series of 3D magnitude and velocity data sets (temporal resolution = 45-49ms). To minimize breathing artifacts and image blurring, respiration control was performed based on combined adaptive k-space reordering and navigator gating [3].
All anatomical and velocity data were loaded into a software package (EnSight, CEI, NC, USA) which offered different data visualization options in order to illustrate the dynamics of 3D blow flow encoded in the velocity images. Visualization was spatially registered with the anatomic information provided by the magnitude data and included vector graphs, 3D stream-lines and time-resolved 3D particle traces.

Results: In concordance with previous works [4,5], undisturbed flow patterns were observed in all volunteers. Figure 1 shows results of 3D stream-line (A) and time-resolved 3D particle trace (B) analysis representing typical systolic blood flow characteristics. Undisturbed and mostly laminar flow patterns with accelerated blood flow in the proximal ascending aorta as well as descending aorta are clearly visible.
In contrast, patients with pathological geometric changes of the thoracic aorta revealed considerable alterations in local blood flow characteristics. For example, a mild aneurysm (4-4.2cm diameter) in a 34-year-old patient resulted in considerable vortical blood flow in the ascending aorta (figure 2). Magnified stream-lines (figure 2A, right) illustrate systolic vortex formation in 3D with considerable circular flow (solid white arrow) that results in spatially constricted and accelerated blood flow near the anterior wall (open white arrow). Temporal evolution of 3D particle traces in figure 3B underline the apparently disturbed flow characteristics and dynamically changing location of the vortex center (solid white arrows) and the obvious movement of the vortex towards the anterior vessel wall. As a result, vortex formation takes up a large fraction of the available ascending aortic lumen and forces the remaining upward flow to the anterior vessel wall (open white arrows) which may result in increased pressure or stress in this region and may stimulate further aneurysm enlargement. Such geometrically triggered changes in blood flow characteristics may therefore be a useful clinical marker for reduced cardiac efficiency and may offer prognostic value regarding aneurysm growth.
Additional findings of major hemodynamic consequences associated with relatively small geometric changes included accelerated and 'cork-screw' type flow patterns in luminal narrowing caused by thrombosis, complex and retrograde flow characteristics for type-A dissection and extensive flow changes and helix formation in the descending aorta in a patient with otherwise unsuspicious graft repair.

Discussion: Time-resolved 3D MR velocity mapping and advanced 3D visualization for patients with aortic pathologies or surgical repair revealed considerable alterations in local blood flow characteristics compared to normal volunteers. Minor geometric changes resulted in major disturbances of local vascular hemodynamics illustrating the potential of MRI for the analysis of complex flow features in 3D. These results raise the question of the usefulness of pure geometrical markers such as aneurysm or stenosis diameter for clinical decision making. The presented methods may offer a more individual assessment of the true effects of pathological changes on vascular hemodynamics an may therefore provide improved clinical markers if and when treatment is warranted. Larger patient studies and further quantitative evaluation strategies (e.g. semi-quantitative description of local flow changes but also derived parameters such as the wall-shear rate or pressure differences) will be vital to proof the reliability of the presented method.

References: 1. Wigstrom L, et al Magn Reson Med 1999;41(4):793-799. **2.** Buonocore MH. Magn Reson Med 1998;40(2):210-226. **3.** Weiger M, et al. Magn Reson Med 1997;38(2):322-333. **4.** Markl M, et al J Comput Assist Tomogr 2004;28(4):459-468. **5.** Bogren HG, Buonocore MH et al J Magn Reson Imaging 2004;19(4):417-427

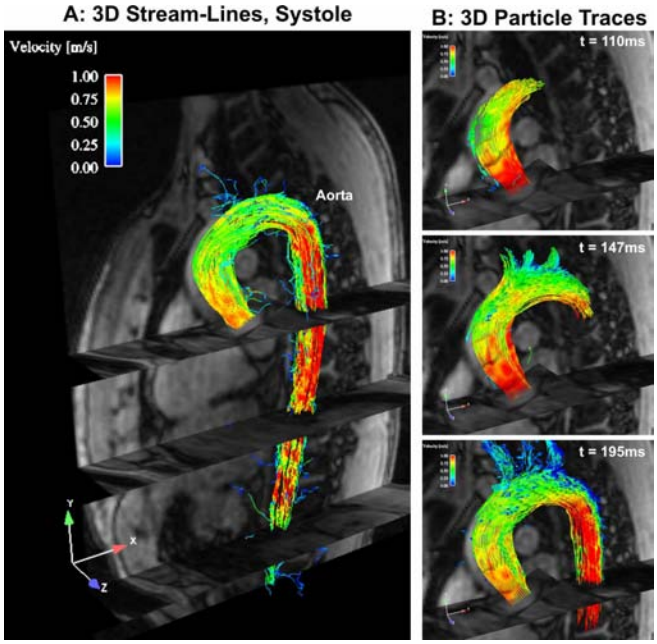

Fig. 1: Unsuspicious 3D blood flow patterns in a healthy volunteer illustrated by systolic 3D stream-lines originating from an emitter plane close to the aortic valve (left, A) and evolution of blood flow in the aorta by 3D particle traces for three systolic time frames (B).

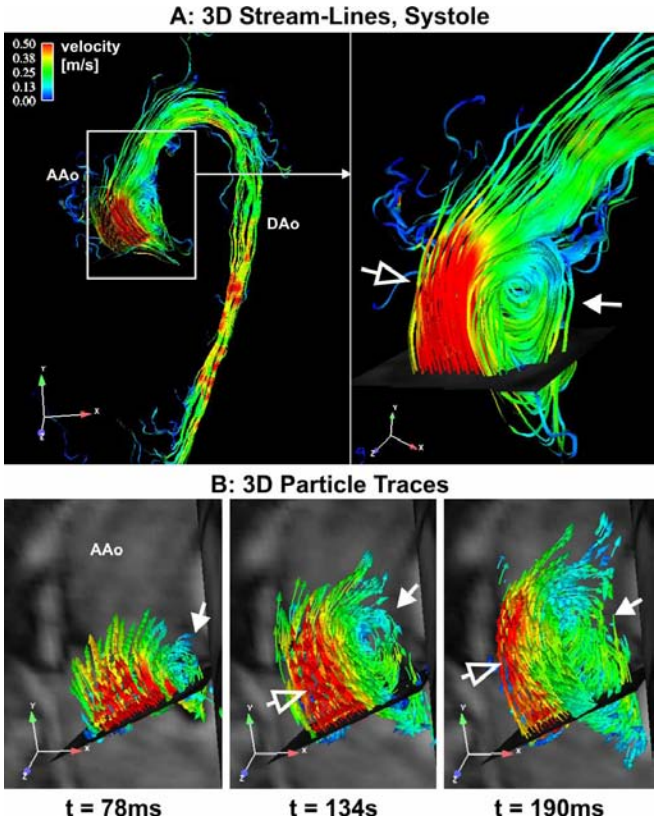

Fig. 2: 3D blood flow visualization in a patient with a mild ascending aortic aneurysm. **A:** 3D Stream-lines in the ascending aorta (AAo) illustrate systolic vortex formation and accelerated blood flow near the anterior wall (open white arrow). **B:** Temporal evolution of 3D particle traces. Dynamics of vortex formation (white arrows) as well as spatially constrained upward flow (open white arrows) are clearly visible.