4-dimensional magnetic resonance velocity mapping of blood flow patterns in chronic aortic dissections at 3T

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Purpose: To determine the feasibility of evaluating flow patterns in patients with chronic thoracic aortic dissection by means of 4-dimensional MR velocity mapping at 3T.

Background: Thoracic aortic dissections are a life-threatening condition. In the acute phase, Stanford Type-A dissections (ascending aorta, arch, and supra-aortic branches) require intervention to prevent death from major secondary complications. The typical intervention is surgical replacement of the vessel segment. However, treated Type-A and chronic Type-B dissection can pose long term risks as well due to aneurysm growth, aortic rupture, or progression of the dissection to the abdominal and iliac vasculature. Our current understanding, however, is limited with respect to the progression and time-course of chronic dissection. Importantly, there are no markers or hemodynamic studies that help to predict the clinical behavior of a chronic dissection. Therefore, it was the goal of this study to apply 4-dimensional (4D) MR velocity mapping to gather insights into flow patterns in chronic thoracic aortic dissection in an effort to apply this new method in the analysis of this important clinical problem and determine if these can provide a better indicator of prognosis than currently used imaging markers.

Methods: 11 ***MR examinations*** were performed in 10 patients (51±18years; 63.4±14.0kg; 6m, 4f) after IRB-approval and written informed consent. Studies were performed on a clinical 3T scanner (TRIO, Siemens, Germany) with an 8-channel phased-array body coil. A referenced 4-point phase contrast sequence with velocity encoding in all three spatial directions was applied. Prospective ECG-gating and adaptive navigator gating for compensation of breathing motion led to imaging times of ~12-18 minutes [1]. Further sequence parameters were adapted to each individual's anatomy: FOV=210-260x320-400; Matrix=74-88x192; TR/TE=6.1/3.7ms; FA=15°; venc=150cm/s. The temporal resolution was 48.8ms. In 9/11 cases, contrast enhancement with gadobenate dimeglumine (Bracco Diagnostics, Princeton, NJ) at 0.1mmol/kg bodyweight was performed for clinical purposes.

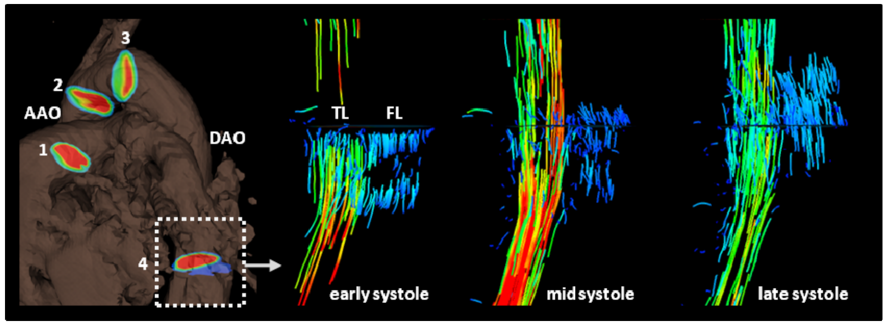

Fig. 1. Left – isosurface of the mediastinal vasculature with color-coded cutplanes manually placed in the ascending aorta (1) , arch (2, 3) and descending aorta (4). Particle trace visualization revealed early backward flow in the descending aorta. TL = true lumen, FL = false lumen; AAO = ascending aorta, DAO = descending aorta.

Data processing included intrinsic corrections for Maxwell terms [2], eddy currents, and velocity aliasing (4 cases). Additionally, a velocity-weighted MR angiogram was calculated and noise masking was performed (MatLab-based home built software (The MathWorks, USA)). Data was then converted for visualization with EnSight (CEI, Apex, NC). A shaded surface display was created on basis of the MR angiogram (Fig 1). 4 analysis planes transecting the aortic lumen orthogonal to the anticipated main flow direction were manually placed: (1) in the ascending aorta (AAO), (2) in the proximal arch, (3) distal aortic arch, and (4) the descending aorta (DAO). This defined four segments of the aorta (analysis plane 1-2: segment A; analysis plane 2-3, segment B; analysis plane 3-4, segment C; analysis plane 4-downstream, segment D). These four planes were used to emit 3D time-resolved particle traces and 3D streamlines (Fig. 2). Streamlines and particle traces were viewed dynamically and rotated or magnified for inspection in any chosen orientation such that all readers could take advantage of the full 3D and time-resolved nature of the data.

Data evaluation consisted of a consensus reading with three cardiovascular radiologists, two with long-standing experience with hemodynamic analyses. The segmentation and visualization quality was visually determined on a 4-point Likert scale (0=poor, 1=OK, 2=good, 3=excellent). All segments were evaluated for helicity (presence, direction), and signs of disturbed flow e.g. additional helices and vortices. On each analysis plane, the presence or absence of a true (TL) and a false lumen (FL) was denoted. Furthermore, the presence of retrograde flow (0=no, 1=minor, 2=major) and its principal orientation (straight/laminar vs. vortical/disturbed) and timing of FL retrograde flow was evaluated.

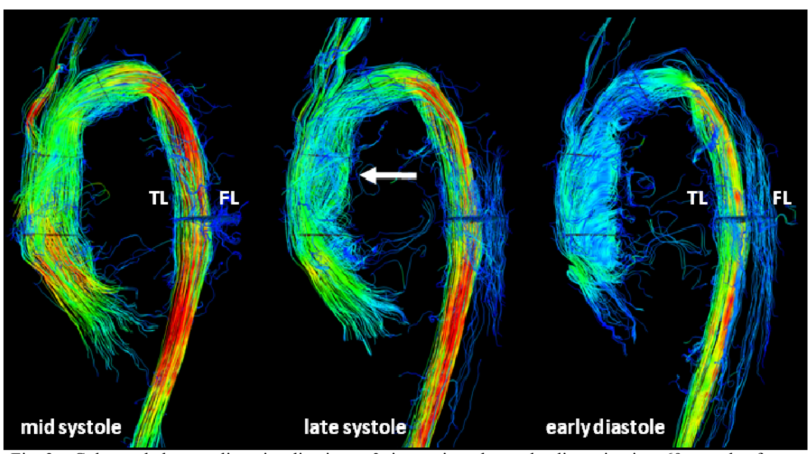

Fig. 2 – Color-coded streamline visualization at 3 time points shows the dissection in a 69yo male after acute Type-A dissection and repair with a supracoronary prosthesis. The chronic dissection in the descending aorta can clearly be appreciated (TL = true lumen, FL = false lumen)

Results: All patients were successfully examined with 4D PC-MRI. Velocity aliasing was successfully removed from all of the datasets. In 8/11 exams, the dissection with low flows could be determined on the basis of the visualization. The other cases presented with large aneurysms and high flow velocities such that a chronic, fenestrated dissection with aneurysm formation was assumed. Segmentation quality was rated good (2/11) to excellent (9/11) in all cases. However, the false luminal flow patterns could not be completely visualized throughout the cardiac cycle with particle traces in any of the cases.

Helicity was present in 36/44 segments. We observed a tendency towards physiological left-handed helicity in segment A (7/11) shifted towards right-handed flow in segments B and C (B: 10/11, C: 7/11) to non-discernible helicity in segment D (8/11). 18 additional vortices and helices were seen in the collective in 10/11 patients. This is in contrast to previously described normal aortic flow patterns [4-5].

Dissections were observed in 16/44 segments/analysis planes. Retrograde flow was present on 37/44 analysis planes of the true lumen (TL), and 15/16 analysis planes of the false lumen (FL). In the TL, retrograde flow was judged strong (12/44) vs normal (25/44), and predominantly vortical (23/44) vs. laminar (16/44). In the FL, retrograde flow was laminar in 8 vs predominantly vortical on 7 analysis planes. Interestingly, retrograde flow in the FL occurred earlier than in the TL in 11/16 analysis planes.

Discussion: The findings illustrate that the analysis of hemodynamic patterns of chronic aortic dissection by means of 4D velocity mapping and 3D visualization is feasible. Markedly altered flow patterns were observed in all patients. Follow-up studies are warranted to determine the significance of these findings. Unexpected patterns such as early systolic FL backward flow observed in most patients could potentially indicate distal re-entry pathways and may be a clinically useful marker of prognosis. Future work will focus on data acquisition strategies [3] with an increased velocity encoding sensitivity spectrumto improve the measurement and visualization of regions with low flow such as the FL.
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References: [1] Markl JMRI 2007 [2] Bernstein MRM 1998 [3] Johnson MRM 2010; [4] Kilner Circulation 1993; [5] Bogren JMRI 1999