Plaques in the Descending Aorta – A New Risk Factor for Stroke? Visualization of Embolization Pathways in the Thoracic Aorta by 4D MRI at 3T

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Introduction: Plaques and thrombi of the ascending aorta and the aortic arch are a major high-risk source for embolic strokes [1]. Next to the semi-invasive reference standard transesophageal echocardiography (TEE), MR imaging is increasingly used for the assessment of aortic plaques [2]. However, previously reported MRI methods lack an assessment of thrombus mobility and cerebral embolization probability in case of plaque rupture. Furthermore, plaques in the descending aorta have received only limited attention as a potential source of thromboembolic strokes [3]. Particularly in presence of severe atherosclerosis and thus increased aortic stiffness, a more detailed analysis of local vascular hemodynamics such as retrograde flow at the site of thrombi is required. Results of a study of 11 patients with severe atherosclerosis indicate the potential of MRI to provide not only stroke risk stratification by identification of plaque localization but also direct evaluation of retrograde flow channels. Specifically, 3D visualization of individual embolization pathways directed towards brain feeding arteries demonstrated the potential role of descending aortic plaques as a high-risk source for stroke.

Methods: All experiments were conducted on a 3T MR system (TRIO, Siemens, Erlangen, Germany). For plaque localization a T1-weighted fat-saturated 3D gradient echo (GRE) sequence with an isotropic spatial resolution of $1mm^3$ was used. Further, contrast-enhanced MR angiography (CE-MRA) was performed after injection of 0.05ml/kg 0.5M Gadolinium contrast agent at 3.5mL/sec. For further analysis of plaque composition T1-weighted GRE imaging was repeated after CE-MRA. Respiration and wall motion artifacts were minimized by ECG gating and respiratory gating. For the assessment of global and local hemodynamics, time-resolved flow-sensitive 4D MRI was employed. Imaging parameters were: velocity sensitivity =150cm/s, spatial resolution $2.1x3.2x3.5mm^3$ in a sagittal oblique 3D volume with rectangular FOV = 400 x $300mm^2$, flip angle = 15°, TE =3.5ms, TR = 6.1ms, band width = 480Hz/pixel [4]. 65 patients with acute stroke were included and underwent both TEE and MRI examination. 11 of 45 analyzed patients demonstrated aortic plaque thickness ≥4 mm and were further evaluated by 3D blood flow visualization using a comercially available software (EnSight, CEI, Apex, USA). Blood flow characteristics were evaluated in consensus reading by time-resolved 3D particle traces (path of virtual mass-less particles tracing the measured time-resolved velocity vector field originating from a used defined emitter plane). For segmental evaluation of flow in the ascending aorta (A), arch (B) and descending aorta (C), emitter planes were inter-actively positioned distal to the aortic bulb (for A), proximal to the brachiocephalic trunk (for B) and distal to the origin of the subclavian artery (for C). Maximum extent of retrograde flow channels in cm were measured for each aortic segment.

Results: Exemplary results of 3D flow analysis for normal and pathological aortic hemodynamics are shown in figures 1 and 2. Figure 1 illustrates systolic and early diastolic blood flow characteristics in a patient with a thrombus in the proximal descending aorta (DAo) (B) compared to representative data from a normal volunteer (A). During systole both volunteer and patient exhibit high and unidirectional flow from the ascending aorta (AAo) into the DAo. In contrast, figure 2B reveals exceeding early diastolic retrograde flow throughout the entire thoracic aorta compared to normal thoracic aortic hemodynamics. During diastole, a marked reversal of blood flow is clearly visible indicating potential embolization pathways in case of thrombus rupture. Similar results are shown in figure 2 for a patient with a large plaque in the proximal Dao. Furthermore, a retrograde flow channel originating from the DAo directed towards the left subclavian artery can clearly be identified, thus proving potential cerebral embolization via the left vertebral artery. Results from all evaluated patients are summarized in table 1 demonstrating considerable retrograde flow for the aortic arch and Dao. For all patients DAO plaques retrograde flow in the DAo was observed.

Discussion: Findings demonstrate the potential of MR imaging to evaluate aortic plaque as a high-risk source for cerebral emboli. The diagnostic impact of MR for the characterization of the aorta is augmented by combining imaging of plaque localization and potential embolization pathways. Most noticeably, MR based 3D blood flow visualization can depict blood flow originating from the site of the aortic plaques or thrombus directed towards the brain supplying arteries. The results indicate that even a thrombus location several centimeters downstream from the left subclavian artery needs to be considered as a high risk factor for stroke. The combination of plaque location in the descending aorta and formation of retrograde flow channels initially passing the left supraaortic arteries may offer an additional explanation for the observed higher incidence to left hemispheric ischemic events.

References: **1.** Harloff A, et al, Stroke. 2006;37:859-64. **2.** Fayad ZA, et al. Circulation. 2000;101:2503-9. **3.** Cohen A, et al. Circulation. 1997;96:3838-41. **4.** Markl M, et al. J Magn Reson Imaging 2006, in press.

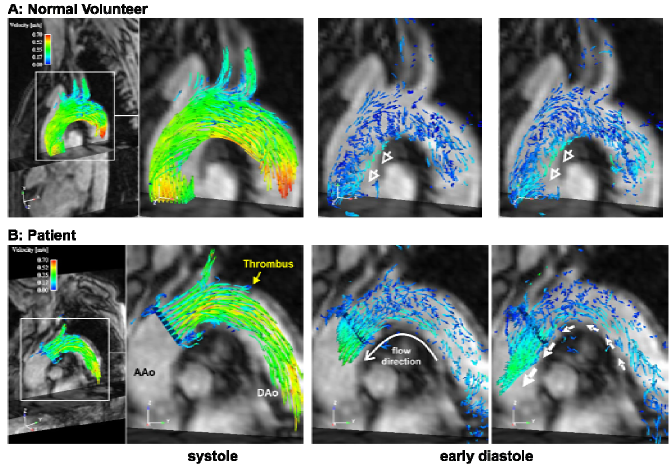

Fig. 1: A: Normal thoracic aortic blood flow characteristics in a healthy volunteer. Systolic filling of the ascending aorta (AAo), arch, descending aorta (DAo) as well as supraaortic vessels is clearly visible. During early diastole the typical formation of a small retrograde flow channel in the ascending aorta (open white arrows) is evident. B: Temporal and spatial evolution of measured 3D blood flow in the ascending aorta, aortic arch and descending aorta in the patient. The location of the thrombus in the proximal descending aorta is indicated by the yellow arrow. In contrast to early diastolic flow in the normal volunteer, an increased flow reversal during diastole (white arrows) originating from the proximal descending aorta and thrombus location can clearly be identified.

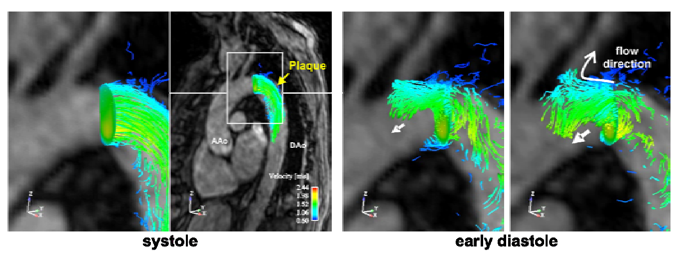

Fig. 2: Time-resolved 3D particle trace visualization of 3D blood flow for a patient with a plaque >4 mm in the distal descending aorta (DAo). The emitter plane was positioned distal to the origin of the subclavian artery. Next to marked early diastolic flow reversal, the direct visualization of retrograde flow into the subclavian artery (white arrow) can clearly be appreciated. In case of aortic plaque rupture, such flow channels could result in a left-sided cerebral infarction via the branching vertebral artery.

	Retrograde Flow [cm]		
Patients with aortic plaques ≥4 mm	**Ascending aorta**	**Aortic arch**	**Descending aorta**
AAo (n=1)	1,0	5,5	2,4
Arcus (n=4)	0,3 +/- 0,5	4,0 +/- 1,5	2,1 +/- 0,8
Proximal DAo (n=4)	1,5 +/- 1,0	4,5 +/- 1,3	**1,9 +/- 1,5**
Distal DAo (n=2)	1,2 +/- 0,3	4,1+/- 0,7	**3,5 +/- 0,2**
Total (n=11)	**0,9 +/- 0,8**	**4,3 +/- 1,2**	**2,3 +/- 1,1**

Table 1: Summary of retrograde flow analysis for 11 patients with aortic plaque ≥4 mm.