Complex Plaques in the Descending Aorta as a Potential Source of Stroke – Visualization of Potential Retrograde Flow into the Supra-Aortic Arteries Using Multi-directional 4D Velocity Mapping at 3 Tesla

A. Harloff[1], J. Simon[1], S. Brendecke[1], W. Wallis[1], D. Assefa[2], A. Frydrychowicz[3], J. Weber[4], J. Hennig[3], C. Weiller[1], and M. Markl[3]

[1]Neurology, University Hospital Freiburg, Freiburg, Germany, [2]Cardiology and Angiology, University Hospital Freiburg, Freiburg, Germany, [3]Diagnostic Radiology, MR Physics, University Hospital Freiburg, Freiburg, Germany, [4]Neuroradiology, University Hospital Freiburg, Freiburg, Germany

Introduction: Complex aortic plaques (thickness ≥4 mm or superimposed thrombi) are one major source of embolic stroke. These plaques are most frequently found in the descending aorta (DAo) [1] but embolism via retrograde transportation of ruptured plaque material into the brain feeding arteries is only considered in conjunction with significant aortic valve insufficiency [2]. In contrast, a previous MRI study indicated generally increased retrograde diastolic aortic blood flow in patients with increased aortic stiffness [3]. Furthermore, a recent study using flow sensitive 4D MRI systematically assessed retrograde flow distal to the left subclavian artery outlet (LSAO) in a cohort of 64 stroke patients. Retrograde flow channels (mean lengths =2.5 cm) connecting the DAo and subclavian artery were frequently found [4]. Particularly, this mechanism was the only explanation for embolic stroke in ~15% of patients indicating that complex plaques in the descending aorta should be considered as high-risk source of brain ischemia. We report the results from an ongoing follow up with consecutive inclusion of acute stroke patients with advanced aortic atherosclerosis using an improved MR protocol and data analysis strategy. Compared to the previous study, improvements include optimized flow-sensitive 4D MRI with parallel imaging, improved spatio-temporal resolution permitting coverage of even end-diastolic flow, three-dimensional fusion of plaque location with retrograde blood flow thus allowing a precise visualization of individual embolic pathways.

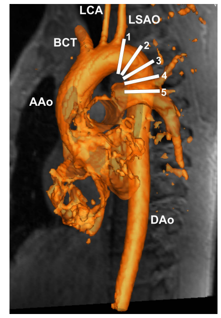

Fig. 1: Assessment of maximum retrograde flow using 3D particle traces originating from a series of emitter planes in the descending aorta (DAo). Planes are positioned distal to the left subclavian artery (LSAO) outlet with a distance of 1 cm between each plane center.

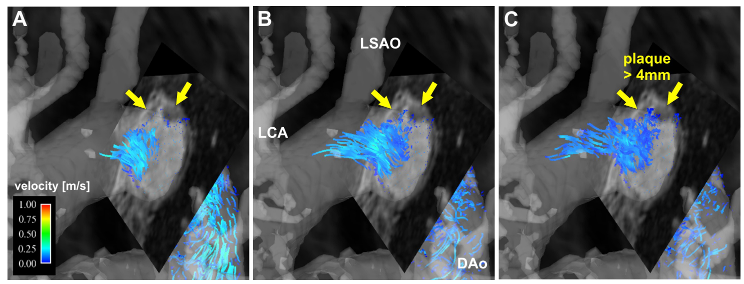

Fig. 2. 3D fusion of a 2D slice showing a complex and protruding atheroma in the proximal DAo (yellow arrows) with the individual retrograde flow for 3 successive diastolic time frames. A direct connection of flow reaching the height of the LSAO and ending close to the LCA with the surface of the plaque can be clearly appreciated.

Methods: To date, 65 consecutive patients with acute cerebral and/or retinal ischemia, age ≥18 years, undetermined stroke etiology prior to transesophageal echocardiography (TEE), aortic plaque thickness ≥3 mm in TEE and suitable for 3T MRI were prospectively included. 11 patients had to removed from final analysis (reconstruction failure: n = 4, limited compliance: n = 4, insufficient data quality: n = 3). Finally, 54 patients were available for analysis. MRI was performed on a 3T routine system using an eight-channel body coil (TRIO, Siemens, Germany). 3D plaque detection and localization was performed as previously described [4, 5]. Flow-sensitive 4D MRI was performed using respiratory navigator gating and the following parameters: (TE/TR =2.6-3.5 ms/5.1-6.1 ms, α=7-15°, temporal resolution=40.8-48.8 ms, spatial resolution=1.7x2.0x2.2 mm^3) [7]. Retrograde flow originating at the proximal DAo was evaluated using 3D flow visualization (EnSight, CEI, Apex, USA) [6]. To evaluate maximum retrograde flow extent, analysis was based on time-resolved 3D particle traces originating from a series of emitter planes virtually positioned distal to the origin of LSAO with an inter-plane distance of 10mm (figure 1). Time-integrated 3D particle traces were successively calculated to identify the maximum reach of retrograde flow, which was defined as the most distal location for which particle traces connected the emitter plane and the LSAO. In addition, MRI vessel wall analysis was performed (J-Vision, Tiani Medgraph AG, Innsbruck, Austria) to generate planes at the site of complex plaques. These 2D slices were imported into the flow visualization tool and additional emitter planes were created at this location to visualize retrograde flow originating directly at the site of the plaque (figure 2).

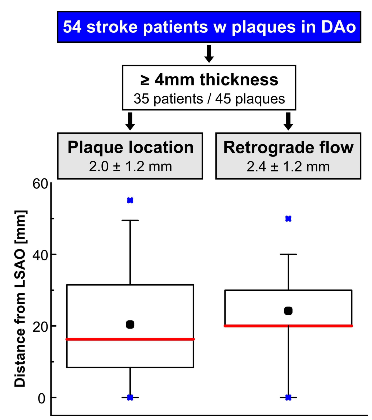

Fig. 3: Results for acute stroke patients with advanced stages of aortic atherosclerosis. In patients with plaques ≥4 mm the similarity of mean plaque distance from the left subclavian artery outlet (LSAO) and mean retrograde flow indicates a potential stroke risk via retrograde embolization. The box-plots show the distribution of maximum retrograde flow next to the locations of the high risk plaques distal to the LSAO. Filled box = mean, red line = median; large box = lower and upper quartile; error bars = range of values within [5.95]% of the data, blue x = min/max values within [1,99]% of the data.

Results: The distribution and extent of retrograde flow for patients with plaque size ≥4 mm is summarized in Figure 3. Mean retrograde flow from the descending aorta was higher in patients with plaques ≥4 mm (2.4+/-1.2 mm) compared to those with plaques <4 mm (1.7+/-1.3 mm). Similar distribution of descending aortic plaque distance for thickness ≥4 mm (box plots in fig 3) indicates the potential for retrograde embolization in these patients. The frequency of retrograde embolic pathways connecting the supra-aortic great arteries with the site of the plaque in the descending aorta is shown in Fig. 3. Retrograde embolization was possible into the LSA in most patients, into the left CCA in one third and into the brachicephalic trunk in every 5th patient.

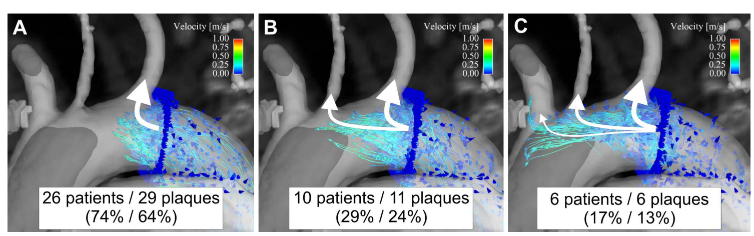

Fig. 3 Exemplary visualization of diastolic retrograde flow connecting the proximal DAo and the left subclavian artery (**A**), the common carotid artery (**B**) and the brachiocephalic trunk (**C**). The white arrows indicate possible embolization pathways in stroke patients. The arrow thickness reflects the frequency of the existence of such flow channels in 35 patients (45 complex plaques) where individual retrograde flow originating from the site of the plaque was visualized.

Discussion: The results of this study demonstrate that marked retrograde flow is a very frequent finding in acute stroke patients. Contrary to current clinical believe, retrograde flow can reach all supra-aortic arteries as shown in this cohort of stroke patients with advanced aortic atherosclerosis. As a result, retrograde embolization from complex plaques in the descending aorta can be responsible for both left and right hemispheric brain infarction. Thus, this MRI protocol was able to demonstrate an otherwise not detectable stroke mechanism and seems to be highly valuable particularly in patients with embolic stroke of undetermined origin.

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References: **1.** Kronzon I et al. Circulation. 2006;114:63-75. **2.** Tenenbaum A et al. Chest. 2000;118:1703-1708 **3.** Bogren HG et. Al. J Magn Reson Imaging 2004;19:417-427. **4.** Markl M. et al. ISMRM 2008 **5.** Harloff A et al. J Neurol Neurosurg Psychiatry 2008;79:540-6. **6.** Markl M et al. J Magn Reson Imaging 2007;25:824-831.