

# Aorto-Iliac Flow-Sensitive 4D MRI: Normal and Altered Flow Characteristics in Abdominal Aneurysms

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**Introduction:** Aortic aneurysms, which can affect 1% to 2% of the population (up 10% in older age groups), follow a complex disease progression which involves formation, growth, and potentially lethal rupture. The highest prevalence is found for infrarenal abdominal aortic aneurysms (AAAs). The shape and composition of AAAs is highly variable and the mechanisms of disease progression are still not fully understood<sup>1,2</sup>. A number of studies have shown that changes in blood flow characteristics in and next to aneurysms can result in altered forces acting at the vessel wall. Such alterations could therefore be new risk factors for aneurysm progression, thrombus formation, or even rupture<sup>3,4</sup>. However, it is challenging to fully characterize complex pulsatile 3D blood flow in AAAs and surrounding vessels and the clinically used diagnosis is typically based on simple geometric parameters (aneurysm diameter, growth rate). Phase contrast MRI with full coverage of 3D vascular structures and all velocity directions (flow-sensitive 4D MRI) has been applied to study complex 3D blood flow in vivo<sup>5,6</sup>. The aim of this study was to evaluate the feasibility of abdominal and peripheral flow-sensitive 4D MRI for the quantification and visualization of normal aorto-iliac 3D hemodynamics and pathological alterations in patients with infrarenal abdominal aneurysms.

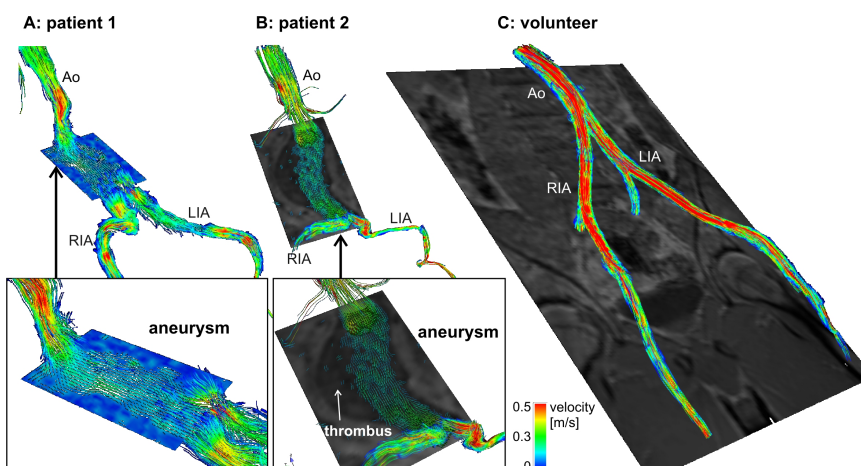
**Methods:** 3D blood flow characteristics in the abdominal aorta and iliac arteries were evaluated in a study with 6 patients with infrarenal abdominal aortic aneurysms (age=68±11 years, all male) and 6 young healthy volunteers (age=28±3 years, 3 male). All measurements were performed at a 3T MR system (Trio, Siemens, Germany) using an ECG gated time-resolved (CINE) 3D phase contrast gradient echo sequence with three-directional velocity encoding (flow-sensitive 4D MRI). Flow-sensitive 4D MRI was performed in a coronal oblique 3D imaging volume which included the abdominal aorta, iliac arteries and proximal femoral arteries. (TE=2.5ms, TR=5.1ms, velocity sensitivity=120 cm/s, flip angle=10°, FOV=325x400mm<sup>2</sup>, spatial resolution= 2.4x2.1x2.1mm<sup>3</sup>, temporal resolution =40.8ms). After Maxwell, eddy current, and velocity-aliasing corrections (MatLab, The MathWorks, USA), flow-sensitive 4D MR data [5] were used for 1) calculation of a 3D phase contrast angiography of the abdominal and peripheral vessels; 2) 3D visualization of blood flow using color coded stream-lines and vector graphs (EnSight, CEI, USA); and 3) quantification of blood flow and peak velocities in analysis planes in the abdominal aorta and the proximal iliac arteries (figure 2).

**Results:** The detailed visualization of aorto-iliac 3D hemodynamics was successfully achieved in all subjects (figure 1). Compared to aneurysm patients, a more homogenous distribution of high systolic blood flow velocities (red color) can be observed in volunteers throughout the abdominal aorta (Ao) as well as right and left iliac arteries (RIA, LIA) (1C). Note the substantially reduced velocities inside the entire aneurysm (magnified images 1A and B) for both patients. The combination of vector graph visualization and magnitude data allowed for the depiction of the remaining flow channel through a partially thrombosed aneurysm (figure 1 B). Similar results were seen in all other patients who showed flow deceleration during passage through aneurysm and sudden flow acceleration distal to the aneurysm in the proximal iliac arteries. The results of flow and velocity quantification are summarized in figure 2 and table 1. For patients, an earlier onset of flow and peak velocities and generally reduced flow in the iliac arteries distal to the aneurysm can clearly be appreciated (figure 2). The flow ratio to the left and right iliac arteries (RIA / LIA flow ratio) was more heterogeneous and significantly increased in patients with abdominal aneurysms compared to controls. Peak systolic velocities in the abdominal aorta and iliac arteries were higher in volunteers (16%-90%) compared to patients. Total flow was similar in the abdominal aorta but significantly reduced in the left and right iliac arteries in patients.

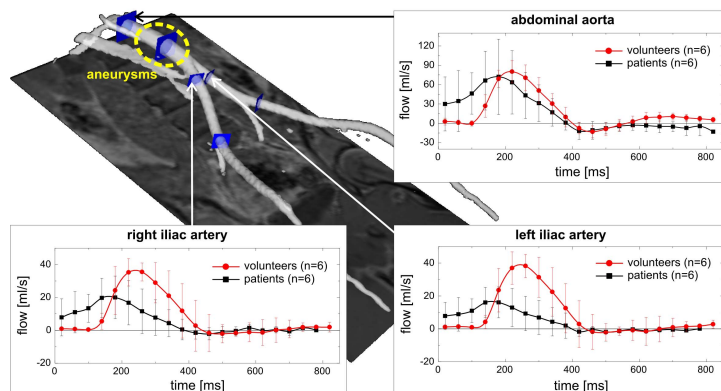
**Discussion:** The findings of this study indicate the feasibility of comprehensive aorto-iliac MR flow analysis and its potential to gain insights into the relationship between aneurysm development and regional vascular hemodynamics. 3D visualization revealed a sudden blood flow deceleration at the aneurysm inlet. Similarly, subsequent flow acceleration directly distal to the aneurysm in the proximal iliac arteries was evident. Such abrupt flow changes may result in considerable fluid shear forces at the aneurysm inlet and outlet. The magnitude and extent of such alterations may thus be an indicator of aneurysm progression or onset of thrombosis. Future studies should thus include more advanced quantitative evaluation of regional shear forces and their correlation with aneurysm geometry, presence of thrombosis, and disease progression. Limitations of this study are related to the small sample size and the absence of an age matched control group.

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**References:** 1. Beckman JA. *Vascular Medicine*. Philadelphia, Pa: Saunders Elsevier Inc; 2006. 2. Beckman JA, et al. *Vascular Medicine*. Philadelphia, Pa: Saunders Elsevier Inc; 2006. 3. Frydrychowicz A, et al. *J Cardiovasc Magn Reson*. 2008;10(1):30. 4. Hope TA, et al. *J Magn Reson Imaging*. 2007;26(6):1471-1479. 5. Markl et al. *J Magn Reson Imaging* 2007;25:824-831 6. Frydrychowicz A, et al. *J Magn Reson Imaging* 2007;25(5):1085-1092.



**Figure 1:** 3D blood flow characteristics (systolic 3D streamlines and vector graphs inside the aneurysms) in the abdominal aorta (Ao) and peripheral arteries in two patients with abdominal aortic aneurysms (A and B) compared to a healthy volunteer (C). RIA, LIA: right and left iliac arteries.



**Figure 2:** Temporal evolution of blood flow in the abdominal aorta as well as left and right iliac arteries for healthy volunteers and patients with abdominal aortic aneurysms. The individual graphs show the flow-time curves averaged over all subjects for each group. Error bars reflect inter-individual standard deviations. The blue analysis planes were used for regional flow quantification.

	peak systolic velocity [m/s]			total flow [ml/cycle]			RIA / LIA flow ratio
	Ao	RIA	LIA	Ao	RIA	LIA	
aneurysm patients	0.55 ± 0.14	0.47 ± 0.05	0.61 ± 0.28	14.1 ± 4.2	3.5 ± 1.8	4.4 ± 2.0	1.3 ± 0.3
healthy controls	0.70 ± 0.03	0.85 ± 0.18	0.78 ± 0.11	13.7 ± 5.4	7.2 ± 2.3	6.8 ± 2.3	1.0 ± 0.1
t-test (p-value)	0.02	<0.01	0.105	0.397	<0.01	<0.05	0.04

**Table 1:** Descriptive statistics of flow quantification in the abdominal aorta (Ao), and left (LIA) and right (RIA) iliac arteries. Mean values were compared using an unpaired one-sided t-test. Significant differences (p < 0.05) are shown in bold.