

Impact of Aortic Valve Replacement on Turbulent Flow Characteristics

Christian Binter¹, Alexander Gotschy^{1,2}, Robert Manka^{1,3}, Simon H. Sündermann⁴, and Sebastian Kozerke^{1,5}

¹Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, ²Dept. of Internal Medicine, University Hospital Zurich, Switzerland, ³Dept. of Cardiology, University Hospital Zurich, Switzerland, ⁴Division of Cardiovascular Surgery, University Hospital Zurich, Switzerland, ⁵Imaging Sciences and Biomedical Engineering, King's College London, United Kingdom

Purpose: Phase-Contrast (PC) MRI allows for time-resolved quantification of velocities in the aortic arch and the assessment of the energy stored in turbulent flow (Turbulent Kinetic Energy, TKE)¹. TKE potentially offers a more direct assessment of the severity of aortic stenosis when compared to parameters derived from velocities measured across the valve using Doppler echocardiography². The complex flow patterns and differences in aortic geometry in patients with aortic stenosis are neglected and therefore results obtained using echocardiography do not necessarily reflect the additional workload of the heart³. In principle, TKE relates to the energy dissipated by viscous forces, which is a key contributor to post-stenotic pressure loss. The objective of the present study was to measure TKE levels in patients before and after valve replacement, and compare them to age-matched healthy controls.

Methods: 14 patients (66±17 years) with aortic stenosis scheduled for aortic valve replacement surgery and 10 age-matched healthy controls (68±5 years) were recruited. Mean Pressure Gradients (MPG) as assessed by echocardiography across the aortic valve ranged from 20 to 75 mmHg in patients. Three patients also received a graft of the ascending aorta. The post-operative MRI examination was performed 8±4 months after valve replacement surgery. Approval of the local ethics committee and informed consent were obtained prior to the study. Data were acquired on a Philips 3T system (Ingenia, Philips Healthcare, Best, The Netherlands) using a 4D Bayesian MultiPoint PC-MRI sequence⁴ with three velocity encoding steps in each direction. Spatial resolution was 2.5 mm isotropic, temporal resolution 26-37 ms depending on the heart rate of the subject. Eight-fold undersampling with k-t PCA⁵ reconstruction was employed, resulting in a nominal scan time of 8 min without respiratory navigator efficiency. TKE levels were calculated by integrating the TKE over the ascending aorta and the aortic arch (TKE_{total}) in peak systole. To account for different cardiac outputs, the results were normalized by the stroke volume. MPG values in healthy volunteers were calculated from the MRI velocity data.

Results: MPG and TKE levels were significantly lower post valve surgery (two-sample t-test, p<0.00001 for both, Fig. 2). Differences between healthy controls and patients with artificial aortic valves were also significant (p<0.01). The relative reduction in TKE_{total} did not correlate with the relative reduction of MPG (R²=0.25, p=0.18), which is also confirmed by a general weak correlation (R²=0.53) between MPG and TKE. The type of valve implanted was not indicative for the reduction in TKE_{total}. Fig. 1 shows pre- and post-operative TKE maps and pathlines in two patients.

Discussion: Aortic valve replacement was found to lead to a significant reduction in TKE levels in all patients. However, values were still significantly higher when compared to age-matched healthy controls. The MPG values measured after valve replacement surgery were classified as 'mild' stenosis. The weak correlation between TKE and MPG warrants further studies regarding the cause of this discrepancy to clarify whether the assessment of TKE provides additional diagnostic value relative to the current echocardiographic reference.

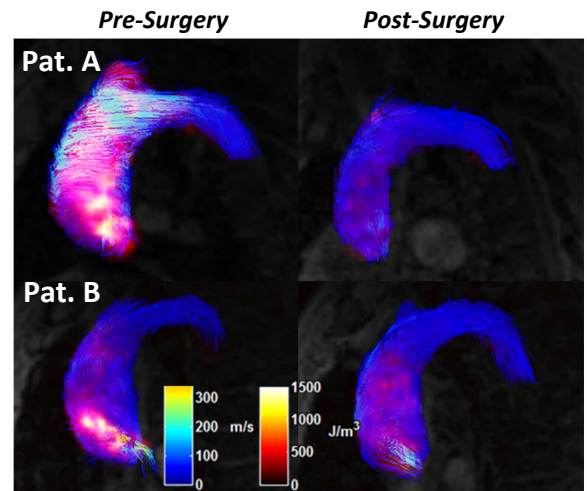


Fig. 1: Systolic TKE maps and pathlines in two patients pre- and post-surgery. Patient A also received an aortic graft because of severe dilatation of the ascending aorta. TKE_{total} values decreased from 0.79 mJ/ml to 0.11 mJ/ml and from 0.38 mJ/ml to 0.30 mJ/ml in the first and second patient, respectively.

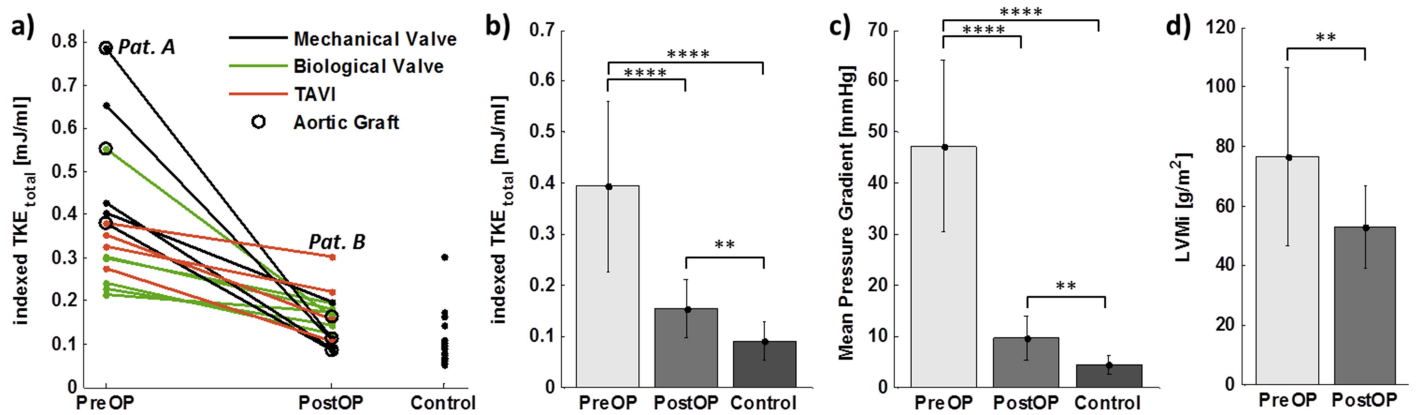


Fig. 2: Pre- and post-operative TKE levels in patients, and comparison with age matched controls (a). The two patients depicted in Fig. 1 are labeled "Pat. A" and "Pat. B", respectively. Mean values and standard deviations for TKE_{total} and MPG are given in (b) and (c). A reduction in left ventricular mass (LVMi, indexed by the Body Surface Area) could be found in all patients upon surgery (d). Significant differences could be found between all groups (** p<0.01, **** p<0.0001).

References:

¹Dyverfeldt et al., J Magn Res Imag 2008, 28:655-663.

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⁴Binter et al., Magn Reson Med. 2013, 69(5):1337-45.

⁵Pedersen et al., Magn Reson Med 2009, 62(3):706-716.