

Assessment of Aortic Stenosis Severity using Bayesian Multipoint Phase-Contrast MRI

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Purpose: The classification of aortic stenosis severity using Doppler sonography is based on the velocities across the valve and does not necessarily reflect the additional workload of the heart¹. Therefore, the decision for surgical intervention is mainly based on subjective criteria such as the symptoms experienced by the patient². Phase-Contrast (PC) MRI offers the possibility of quantifying the energy dissipated in turbulent flow (Turbulent Kinetic Energy, TKE)³, thereby potentially offering an objective measure of disease severity. A first study showed good correlation of MRI based TKE assessment with energy loss as determined by Doppler sonography⁴. In this work we present preliminary results from an ongoing study in a larger patient population, and investigate inter- and intra-observer variability.

Methods: For this study, 16 patients (69±13 years) with moderate to severe aortic stenosis and 10 age-matched healthy controls (68±5 years) were recruited. Mean Pressure Gradients (MPG) across the aortic valve ranged from 20 to 68 mmHg in patients, all subjects had an ejection fraction of >50%. 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 sequence⁵ with three velocity encoding steps in each direction. Spatial resolution was 2.5 mm isotropic, temporal resolution 24-44 ms depending on the heart rate of the subject. Eight-fold undersampling with k-t PCA⁶ reconstruction was employed, resulting in a nominal scan time of 8 min without respiratory navigator efficiency. The energy loss (TKE_{total}) was calculated by integrating the TKE over the ascending aorta and the aortic arch for all time points t. The TKE turnover time was assumed to be 70 ms according to experimental data (not shown here). The integration volume V is illustrated in Fig. 1. To account for different cardiac outputs, the results were normalized by the stroke volume (SV):

$$TKE_{total, indexed} = \frac{\int_t \int_V TKE}{SV}$$

Data analysis for each dataset was performed twice by two blinded observers. Segmentation of the aortic arch was carried out manually in Matlab (Mathworks Inc., Natick, MA, USA) based on complex difference images and TKE values during mid-systole. The MPG for the healthy volunteers was calculated from the MRI velocity data.

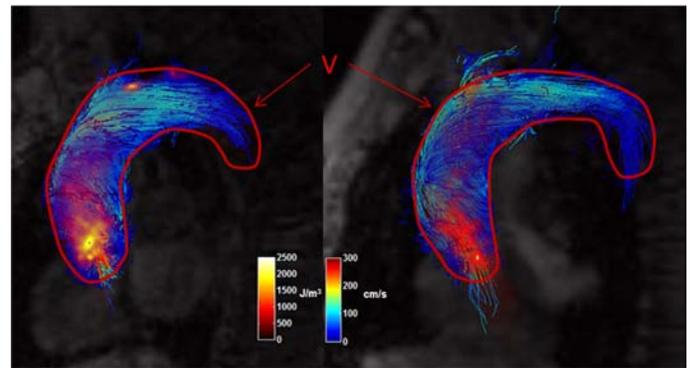


Fig. 1: Combined systolic TKE maps and pathlines in two patients with similar Mean Pressure Gradients as determined by echo (42 vs. 41 mmHg). It can be seen that the TKE levels vary significantly, the total TKE indexed by stroke volume were 2.1 and 1.0 mJ/ml, respectively.

Results: Data acquisition was successful in all subjects. Fig. 1 shows example TKE maps and pathlines in two patients with similar MPGs (41 vs 42 mmHg). The correlation between MPG and TKE as determined by PC-MRI ($R^2=0.58$) is given in Fig. 2a. Symptomatic/asymptomatic subjects are indicated. In 7 patients either no information was available, or confounding diseases such as Coronary Artery Disease were present. Intra- and inter-observer variability are shown in Fig. 2b,c. Mean differences were 6.6±5.0% and 7.9±5.9% for intra- and inter-observer variability, respectively.

Discussion: The comparison of two patients which received the same disease severity classification using ultrasound show similar flow patterns but differing TKE levels indicating that flow velocities alone are not the decisive factor on energy loss. The results also show a significant difference between healthy controls and patients. In general only a weak correlation between TKE and MPG was found. At the current point of this on-going study, a classification based on TKE according to presence/absence of symptoms is not conclusive. This may partly be related to the low number of asymptomatic patients included and the inter- and intra-observer variability in analyzing the data. For a statistically significant conclusion about the differences in energy levels between symptomatic and asymptomatic subjects a larger patient population is required. To achieve a higher robustness, semi- or fully-automatic segmentation tools are desired to reduce operator dependency.

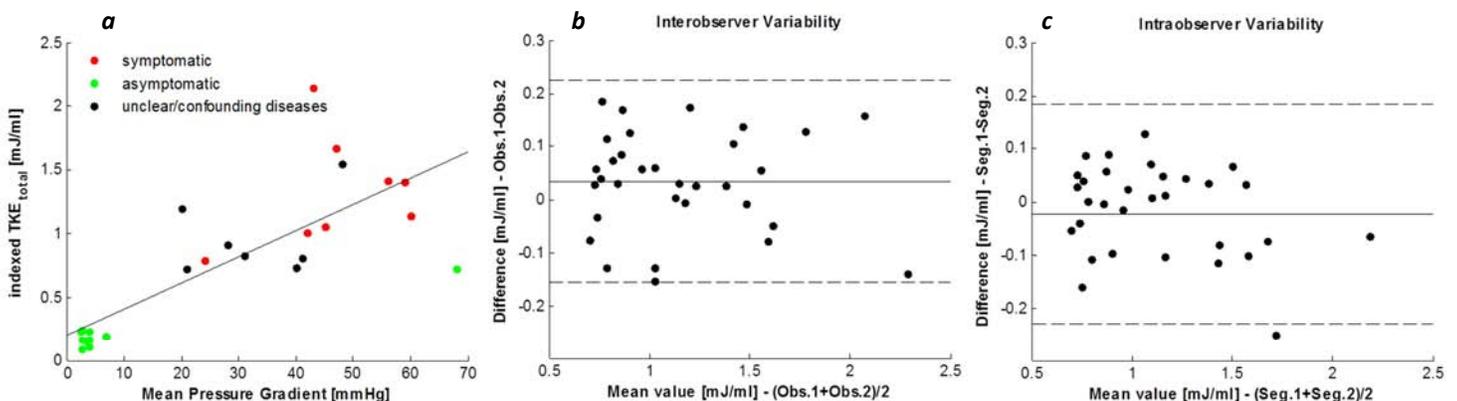


Fig. 2: Linear regression between Mean Pressure Gradient and indexed TKE_{total} (a). Asymptomatic/symptomatic patients are indicated. Inter- and intra-observer variability of TKE_{total} is given in (b) and (c).

References: ¹Akins et al., J Thorac Cardiovasc Surg 2008, 136:820-33.

²ESC/EACTS, Eur Heart J. 2011, 33(19):2451-96.

³Dyverfeldt et al., J Magn Reson Med 2008, 28:655-663.

⁴Dyverfeldt et al., JACC Cardiovasc Imaging. 2013 Jan;6(1):64-71.

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

⁶Pedersen et al., Magn Reson Med 2009, 62(3): 706-716.