Turbulence Mapping Extends the Utility of Phase-Contrast MRI in Mitral Valve Regurgitation

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Introduction: Quantification and visualization of blood flow play a central role in the assessment of valvular heart disease. The flow associated with mitral valve insufficiency is characterized by high velocities and turbulence which limits its assessment using current clinical MRI methods. Rapid Fourier velocity encoding approaches have been developed to measure peak velocities [1]. In turbulent flow, where blood constituents and endothelial cells are subjected to abnormal stresses, the presence of multiple spin velocities within a voxel reduces the MRI signal magnitude; this signal void phenomenon is often used for qualitative or semi-quantitative evaluation of valve lesions. Recently, a framework for the quantification of turbulence based on a generalized usage of the phase-contrast (PC) MRI signal was presented [2]. In addition to mean velocity assessment by conventional phase subtraction, generalized PC-MRI allows for the measurement of the intravoxel velocity standard deviation (IVSD) by exploiting the effects of turbulent flow on the PC-MRI signal magnitude. This approach has been shown to be feasible for the in-vivo assessment of turbulence [3]. Here, we present our experiences with generalized PC-MRI in patients with significant mitral valve regurgitation.

Materials and Methods: Five patients with severe mitral valve regurgitation caused by posterior leaflet prolapse were included in the study. Three-dimensional cine PC-MRI data were acquired during free breathing using a flow-compensated gradient-echo pulse sequence with interleaved three-directional flow-encoding and retrospective cardiac gating. For anatomical orientation, b-SSFP cine images were acquired. All measurements were made on a clinical Philips Achieva 1.5 T scanner.

The peak velocities of the regurgitation flow were estimated to around 6 m/s by echocardiography. Setting the PC-MRI velocity encoding range (VENC) parameter to match velocities around 6 m/s would give suboptimal velocity-to-noise ratios in other intracardiac regions; therefore, the peak velocities in the regurgitation jet were disregarded. Instead, the VENC was set to 150 cm/s in order to focus on acquiring data suitable for turbulence quantification in the regurgitation flow and evaluation of ventricular flow. Additional imaging parameters included: TR = 5.9-6.5 ms, TE = 3.4-3.7 ms, flip angle = 8°, voxel size = 3x3x3 mm^3, SENSE = 2. To further reduce scan time, two k-space lines were acquired per cardiac phase. Respiration effects were minimized by using navigator gating with a window size of 5 mm and 10 mm in the inner 25% and the outer 75% of the k-space, respectively. Scan time, excluding the navigator gating efficiency, was 10-15 minutes. On the scanner, all data were corrected for concomitant gradient field effects. Subsequent post-processing made corrections for background errors and phase wraps.

From the single PC-MRI dataset acquired in each patient, the mean velocity was computed by conventional phase subtraction whereas the IVSD was obtained from the magnitude ratio of two PC-MRI flow encoding segments acquired with different first gradient moments [2]. The IVSD in three directions allows for the computation of the turbulent kinetic energy (TKE), a direction-independent measure of turbulence intensity.

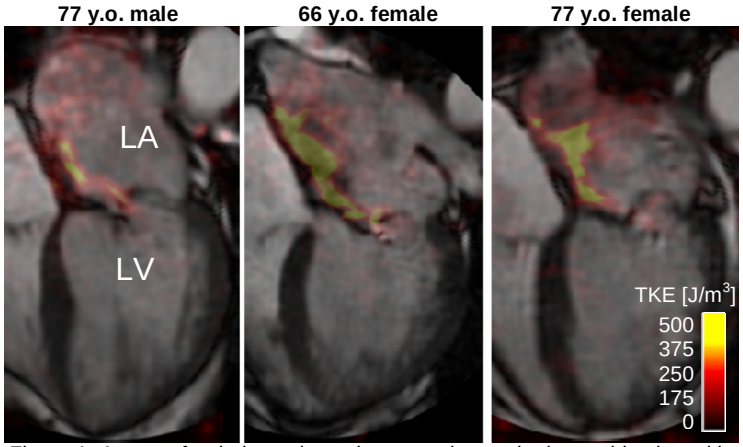

Figure 1. A map of turbulence intensity, at peak systole, in combination with a semi-transparent b-SSFP 4-chamber image in three patients with severe mitral regurgitation. The turbulence maps, which were extracted from the 3D data volume, are color-coded according to turbulent kinetic energy (TKE). A marked increase in turbulence intensity is observed along the course of the regurgitation jet as it follows the interatrial septum.

Results: In all the patients, the turbulence data showed elevated turbulence intensity in the atrium along the course of the regurgitant jet (Fig. 1). In four of the patients, the jet was directed towards the atrial septum; one subject had a more central regurgitation jet. As expected, with VENC set to 150 cm/s the high velocities in the regurgitant flow were severely aliased and could not be unwrapped. Intraventricular flow visualization with particle trace technique remained feasible (Fig. 2).

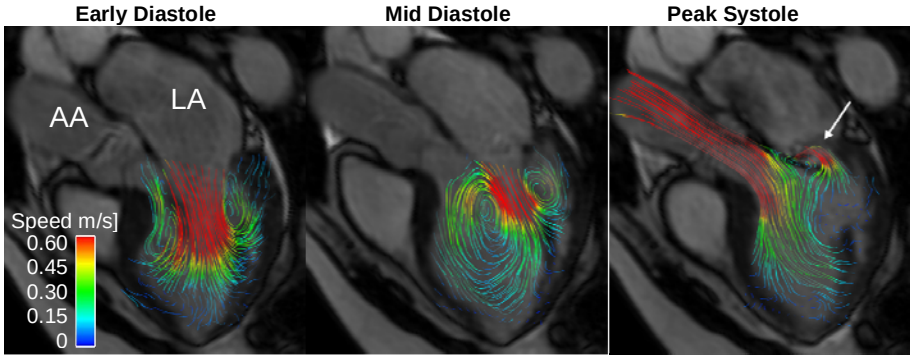

Figure 2. Streamline visualization of left ventricular blood flow at three different cardiac phases in a patient (77 y.o. female) with severe mitral regurgitation combined with a b-SSFP 3-chamber image. Arrow: In peak systole, the velocities in the regurgitation flow are aliased, cutting off the traces at the origin of the regurgitant jet. AA: Ascending aorta. LA: Left atrium.

Discussion: In five patients with severe mitral valve regurgitation, generalized PC-MRI was used successfully to assess turbulence in the left atrium and the mean velocity field in the left ventricle from a single PC-MRI scan. These encouraging results suggest that generalized PC-MRI is consistently able to provide measurements of not only mean flow velocities but also turbulence intensity. Quantitative in-vivo assessment of turbulent flow may provide novel perspectives on risk stratification of patients with valve disease and could be useful in the evaluation of different treatment strategies.

References: [1] Carvalho JL & Nayak KS. MRM 2007;57:639-46. [2] Dyverfeldt P, et al. MRM 2006;56:850-58. [3] Dyverfeldt P, et al. JMRI 2008;28:655-63.