Segmentation and Characterization of Vortical Flow Patterns in MRI Phase-contrast Velocity Data

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INTRODUCTION: Phase-contrast magnetic resonance imaging (PC-MRI) provides a unique method to accurately estimate velocities within a 3D region during the complete cardiac cycle. This 4D-flow technique enables studies of flow patterns in the heart and great vessels to provide new physiological insights [1,2]. Based on the acquired velocity data, particle trace visualization can be used to create an informative display of the velocity field. Still, this visual approach requires a lot of experience to locate and describe flow structures of interest, and searching through the complete dataset for any unknown flow patterns is extremely time consuming. An automatic and objective characterization of flow patterns would be of great importance for the definition of normal and abnormal flow, and to subsequently make 4D-flow studies more applicable in a clinical setting. In this study, new image processing tools have been developed in order to locate and quantify flow patterns of interest.

MATERIALS AND METHODS: A set of vector valued filters are applied on each time-frame of the acquired PC-MRI data. Since no a-priori information exists regarding the orientation of the flow structures, 6 differently oriented filters are used. The filter responses are combined using a tensor representation. The largest Eigenvalue or the tensor norm is used to find the similarity between the used filter and the actual velocity data [3]. Using a range of filter diameters, the best match is computed and the corresponding region in 3D space is marked. From the best matching filter in each voxel, a number of parameters can be derived, including vortex size and pitch. Within the segmented regions, additional parameters can subsequently be estimated based on the original velocity data. Parameters of interest for objective characterization of vortical flow are vorticity, angular velocity, helicity and kinetic energy.

A volume rendering tool was develop to visualize the resulting flow feature parameters. The commercially available EnSight software also gives the possibility to compare the derived parameters with particle traces calculated from the velocity data.

RESULTS: An example of a volume rendering of vortex core similarity is shown in Figure 1. Further calculations based on a range of filter diameters are subsequently combined and results in a scalar volume that in each voxel contains the probability of being part of a vortical flow structure (see Figure 2). Figure 3 shows a comparison with streamlines calculated from the same velocity data.

CONCLUSION: Automatic segmentation of vortical flow patterns provides an objective approach to characterization of 4D-flow data. Volume rendering of the results gives a quick overview, where regions of vortical flow can be easily identified. Further studies using for example streamline visualization can be performed in these regions to display more details of the flow field.

REFERENCES:
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2   Markl, M., et. al., Time-resolved three-dimensional phase-contrast MRI. JMRI 2003;17
3   Heiberg E, et. al., Three-dimensional flow characterization using pattern matching. IEEE Transactions on Visualization & Computer Graphics 2003;9(2)
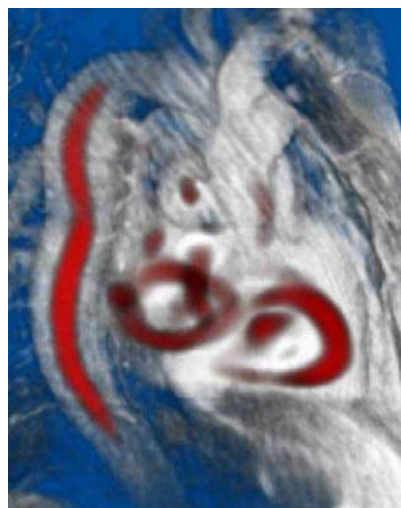
Figure 1. Volume rendering of the vortex core similarity showing ring vortices in both the left and right ventricles of the heart and the swirling flow in the descending aorta.
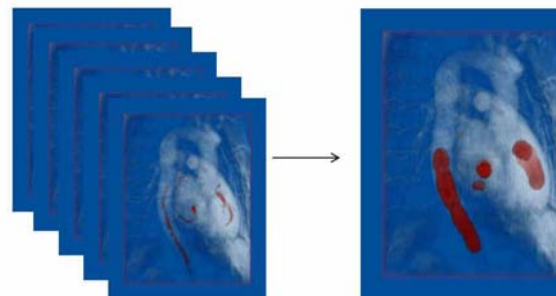

Figure 2. Vortex core similarities from a range of filter diameters are combined in order to estimate the regions occupied by vortex like flow.
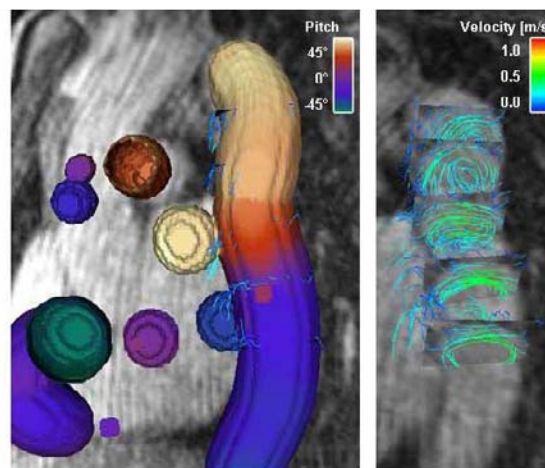

Figure 3. Left: Detected regions with vortical flow (surface renderings color coded according to pitch angle). Right: Streamline visualization of the same region in the descending aorta in late systole also shows a rotating flow pattern.