

Blood Flow Patterns in the Left Ventricle of the Healthy Human Heart Described by Lagrangian Coherent Structures Computed from 4D Phase Contrast MRI



Johannes Töger^{1,2}, Johannes Ulén^{1,3}, Marcus Carlsson¹, Håkan Arheden¹, Gustaf Söderlind² and Einar Heiberg¹

¹Cardiac MR Group, Dept. of Clinical Physiology, Lund University, Skåne University Hospital, Lund, Sweden

²Numerical Analysis, Centre for Mathematical Sciences, Lund University, Lund, Sweden

³Mathematical Imaging Group, Centre for Mathematical Sciences, Lund University, Lund, Sweden

johannes.toger@med.lu.se

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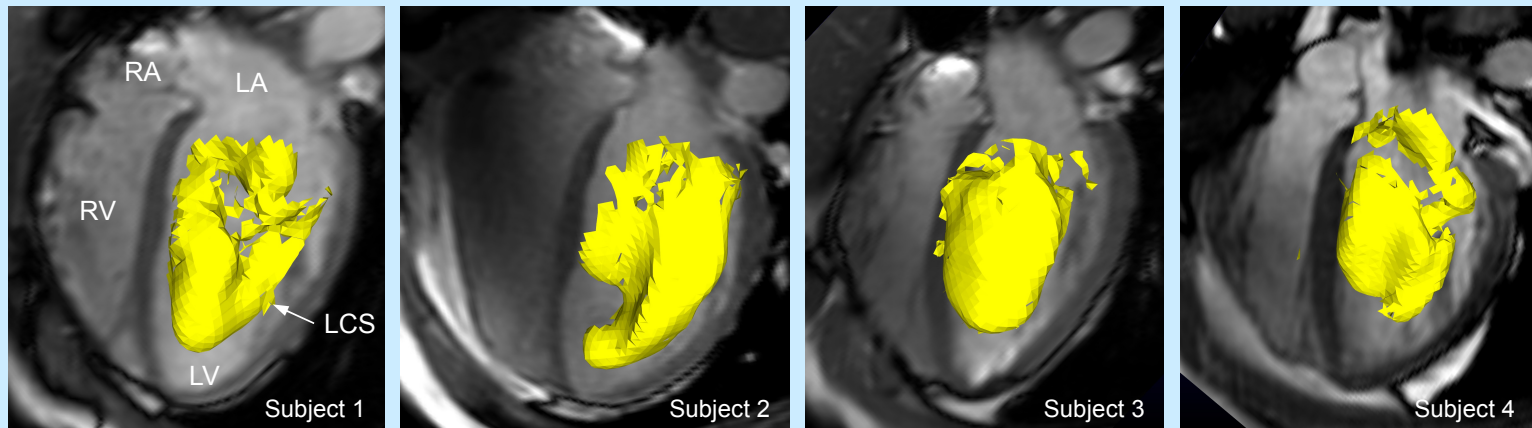


Figure: LCS visualizations during the filling of the left ventricle in four healthy volunteers. All images show the late diastolic phase, just before the atrial contraction. In subject 1, labels denote the left ventricle (LV), right ventricle (RV), left atrium (LA), right atrium (RA) and the diastolic inflow LCS (yellow). The same view is used for all images. The inflow LCS in subject 1 is located in the middle of the ventricular lumen. In subject 2, the LCS appears curved, suggesting a swirling flow. In subject 3, the blood entering the ventricle is located in the middle of the ventricle, similar to subject 1. In subject 4, the diastolic inflow LCS does not extend to the apical third of the ventricle.

Background

Blood flow patterns are a fundamental aspect of cardiac function, and abnormal function may be reflected in the flow patterns. Three-dimensional, time-resolved, three-component phase contrast MRI (4D PC-MRI) can be used to measure the flow, but evaluating flow data is a complex task. Lagrangian Coherent Structures (LCS) [1] is a recently developed visualization method that may offer a simplified view by partitioning the flow into regions of different dynamics.

Purpose

The purpose of this study was to compute and visualize the *diastolic inflow LCS*, which shows the boundary between the diastolic inflow jet and the blood already in the ventricle, in four healthy volunteers. Furthermore, we aimed to describe similarities and differences between the subjects.

Materials and Methods

Three-dimensional, time-resolved, three-component Phase Contrast MRI (4D PC-MRI) was used to acquire velocity fields over the whole heart in four healthy volunteers. The spatial resolution was 3 mm isotropic, temporal resolution was 50 ms and VENC 100 cm/s. LCS in the left ventricle were computed using an in-house developed algorithm and visualized together with anatomical cine images in the visualization software package Ensight (CEI, USA).

Technical Implementation

To extract the LCS, a flow map was first computed. The flow map describes the path taken by all particles in the flow from early diastole and forward in time. Since the desired LCS separates blood with different origins, the flow map will have a large spatial variation near the LCS. Surfaces with locally high variation of the flow map were extracted using an in-house developed algorithm.

Results

The figure shows the location of the diastolic inflow LCS in late diastole in all four subjects. Subjects 1 and 3 exhibit a similar LCS shape, while subject 2 has a curved LCS. The LCS in subject 4 does not extend to the apical third of the ventricle.

Conclusion

The shape of the LCS describing the boundary between blood flowing into the left ventricle and blood already in the ventricle from previous heartbeats was successfully visualized in all subjects. The shape of the LCS varied between the subjects.