Cardiac Function Analysis in Multi-cycle Real-time MRI

Teodora Chitiboi[1,2], Anja Hennemuth[1], Lennart Tautz[1], Markus Hüllebrand[1], Jens Frahm[3], and Horst Hahn[1]
[1]*Fraunhofer MEVIS, Bremen, Bremen, Germany,* [2]*Jacobs University, Bremen, Bremen, Germany,* [3]*Max Planck Institute for Biophysical Chemistry, Göttingen, Germany*

Introduction: Recently developed real-time MRI techniques allows for image acquisition with high temporal resolution up to 20ms. Cardiac image sequences can be acquired without the need for breath holding or ECG synchronization, thus improving patient comfort and reducing artifacts caused by averaging slightly different or even irregular heart cycles (Fig.1). Manual analysis of such image series is no longer feasible because of their length (10 heart beats are recorded in several hundred frames). However classical segmentation algorithms are not designed to cope with the T1-contrast of these images which differ from regular cine MRI with SSFP contrast. We have implemented and evaluated specialized segmentation and visualization techniques for extracting the myocardium in consecutive heart cycles and showing the variability of heart function over time. The multi-cycle analysis of heart function can provide valuable information, assisting the diagnosis of various heart conditions and monitoring of treatment.

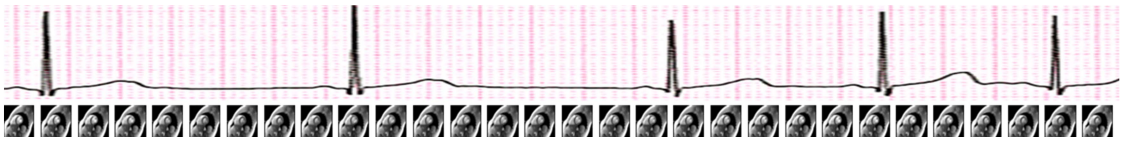

Fig. 1 Real-time cardiac MRI image series (short-axis) densely sample multiple consecutive heart cycles without the need for averaging accurately capturing the motion.

Methods: The emerging real-time MRI acquisition technique [1,2] is based on undersampled radial FLASH sequences with image reconstruction by regularized nonlinear inversion (NLINV), which enables capturing rapid motion-induced changes. This allows for imaging of patients unable to hold their breath, but also reflects the effects of breathing or arrhythmia over the image sequences. The data was acquired with a Siemens Trio 3T scanner at a 1.6 mm in-plane resolution and 6 mm section thickness. The subjects were healthy volunteers as well as a patient with arrhythmia.

The image series are analyzed in the Fourier domain to find the region with the most rapid changes, while filtering out the slow breathing motion. A point close to the heart center is located using Hough transform [3]. The automatic segmentation method employs an object-based technique [4]. Each individual image is first partitioned based on local similarity into regions of about 50mm^2. These are stored in an attributed relational graph that encodes the local neighborhood information. The regions are classified into different tissue types (blood, muscle or lung) based on their intensity statistics and connected regions of the same class are merged. The shape and neighborhood relations of the newly created structures are used to iteratively adapt the blood-to-muscle intensity threshold for each individual time frame. This adaptive classification accounts for the changes in intensity and contrast that appear in the image series throughout a heart cycle. The process is repeated until the region corresponding to the left-ventricular (LV) bloodpool has the desired shape and intensity properties. To overcome the low contrast, the boundary between the myocardium and liver is inferred from the relative positions of the lung and right ventricle (Fig.2 - left). The resulting LV bloodpool and myocardium regions are further refined by elliptic fit. The final contours are smoothed by morphological operations. Time frames which are difficult to segment because of low contrast are independently identified and corrected by propagating contours from neighboring frames using non-rigid registration [5]. After segmentation, the cardiac cycles are automatically determined based on the local extrema in the blood volume time curves (Fig. 4 - top).

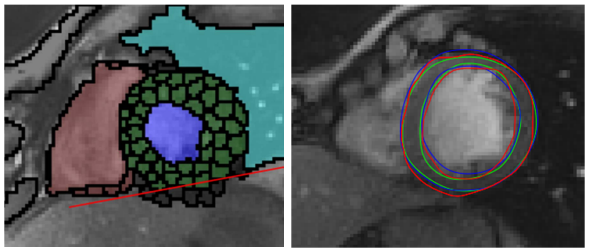

Fig. 2 (Left) Image context: LV blood pool (blue), RV (red), lung(cyan), myocardium objects (green), and red line separating myocardium from liver. (Right) Myocardial contours segmented automatically (red) and by the two observers (blue and greed).

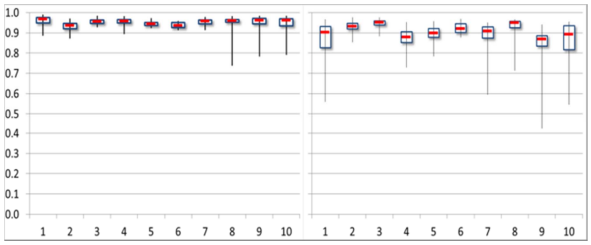

Fig.3 (Left) Epicardium and (right) endocardium dice score for the segmentation of 10 real-time cardiac MRI series (short-axis).

Results: We have tested our automatic segmentation method against manual segmentations from two observers (Fig. 2 - right) with good results. The algorithm was applied to 10 short-axis real-time slices consisting of 300 to 700 frames (10 to 15 consecutive heart cycles). We have obtained and average dice score of 95.4% for the epicardium and 89.8% for the endocardium (the statistics for each individual dataset are presented in Fig.3). This enabled the visualization of sets of 10-15 consecutive heart cycles for each image series and the analysis of inter-cycle variations of functional parameters. The effects of breathing, physiologic maneuvers (e.g., Valsalva), stress, and arrhythmia can be observed in the temporal blood volume curves (Fig. 4), which are inaccessible by regular cine MRI.

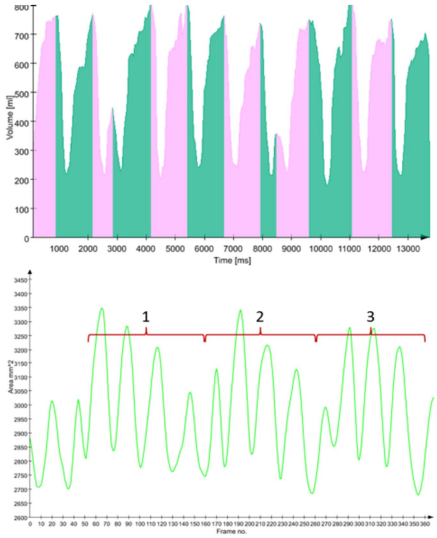

Fig.4 (Top) Blood pool as a function of time for multiple heartbeats (alternating colors) in mid-ventricular short-axis slice. Patient presents extrasystole due to arrhythmia which result in smaller end-diastolic volume. (Bottom) LV area as a function of time reveals the influence of breathing in a normal subject. 3 breathing cycles are highlighted.

Conclusions: Using an object-based automatic segmentation of the heart muscle in multi-cycle real-time MRI sequences, we could inspect the contractile motion of the LV myocardium over several consecutive heart beats. A current limitation is the restriction to individual 2D sections of the heart, because real-time images are acquired as serial cross-sectional views that cannot be directly stacked into a 3D volume. Future extensions will stitch individual sections by matching similar cardiac cycles.

References:

[1] Uecker et al. NMR in Biomedicine 2010.
[2] Zhang et al. Cardiovasc. Magn. Reson. 2010.
[3] Yip et al. Pattern Rec. 1992.
[4] Chitiboi et al.VMLS EuroVis 2013.
[5] Tautz et al. IEEE ISBI 2010.