Analysis of the Left Ventricle after Myocardial Infarction combining 4D Cine-MR and 3D DE-MR Image Sequences

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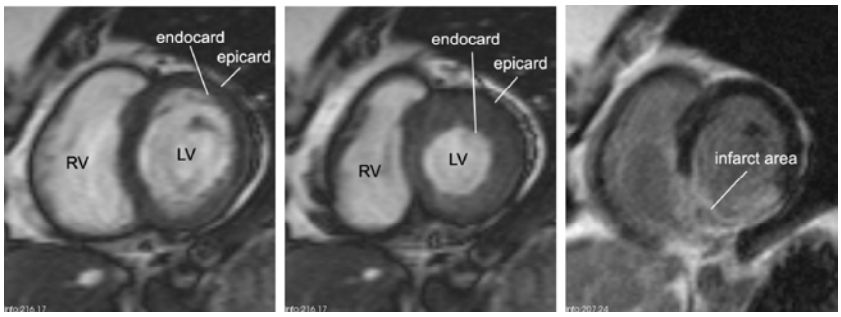
Abstract. Spatial-temporal MR image sequences of the heart contain information about shape and motion changes and pathological structures after myocardial infarction. In this paper a software system called HeAT for the quantitative analysis of 4D MR image sequences of infarct patients is presented. HeAT supports interactive segmentation of anatomical and pathological structures. Registration of Cine- and DE-MR image data is applied to enable their combined evaluation during the analysis process. Partitioning of the myocardium in segments enables the analysis with high local resolution. Corresponding segments are generated and used for inter/intra patient comparison. Quantitative parameters were extracted and visualized. Parameters like endocard movement in the infarcted area of 6 infarct patients were computed in HeAT. Parameters in the infarct area show the expected dysfunctional characteristics. Based on theses parameters passive endocardial movement and myocardial areas with decreased contraction were identified.

1 Introduction

Myocardial infarction is one of the most common diseases in Germany. The infarcted area loses its ability to contract. This is attributed to left ventricle (LV) remodeling. LV remodeling is an important element in the progression of cardiac insufficiency characterized by wall thinning and chamber dilation for example [1]. It is a clinical problem to get quantitative parameters characterizing LV remodeling. New MR imaging techniques provide a non-invasive evaluation of anatomical and functional (local and global) parameters of the beating heart. In this paper spatial-temporal 4D Cine-MR and spatial delayed enhancement (DE)-MR image sequences are combined to extract quantitative image parameters after myocardial infarction (Fig. 1).

In this paper a software system called HeAT for the quantitative analysis of 4D MR image sequences of infarct patients is presented. Recently several software tools for quantitative analysis of spatial-temporal cardiac MR data were

Fig. 1. Two frames of a Cine-MR image sequence in endiastolic (a) and endsystolic (b) phase. Infarct area can be identified in the corresponding DE-MR image (c).



(a) (b) (c)

presented. The computation of global and local parameters in Cine-MR is supported rarely. Typically local parameters are computed and visualized using the 17 segment model. These parameters are limited for detailed evaluation of LV remodeling. Recently studies documented the mechanism of LV remodeling. Especially motion and shape changes of the myocardium in the infarct border zone were analyzed. Here the border zone was verified in Cine-MR manually using e.g. contrast echocardiography or delayed enhancement data for visual assistant. Generally this manual analysis is user-dependent and limited for inter/intra patient comparison. Other studies have underscored the impact of microvascular obstruction (MO) on the development of LV remodeling [2]. Due to the facts above the influence of MO is still poorly understood.

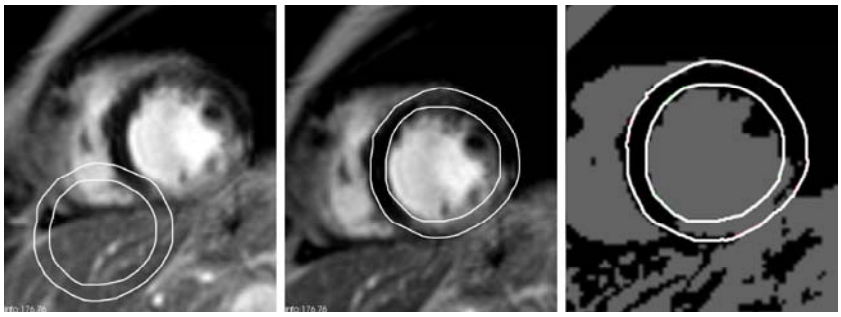
2 Methods

Computation of quantitative parameters in cardiac MR data requires localization and combination of the anatomical and pathological structures. Typically over 200 spatial-temporal Cine-MR and 7-12 spatial DE-MR images are acquired for each patient during breath-hold sequences.
Segmentation and registration are necessary before the automatic algorithms for parameter extraction can be applied to evaluate the degree of myocardial infarction. Manual segmentation is used to outline myocardial structures in Cine-MR. Here identification of pathological structures is not possible, but in DE-MR these structures can be recognized. Therefore a data-driven method is applied in DE-MR images for segmenting pathological structures using user-defined seed points within the healthy myocardial area. Based on their intensities mean $\bar{x}_{intensity}$ and standard deviation $\sigma_{intensity}$ are calculated. Due to the homogeneous intensity values of healthy myocardial tissue, voxels in the myocardium with intensities higher than

$$x_{threshold} = \bar{x}_{intensity} + 2 \cdot \sigma_{intensity} \tag{1}$$

are regarded as necrotic (Fig. 2).

Fig. 2. Visualization of the results of direct contour overlay before (a) and after (b) rigid registration. Segmentation of the infarct area using $x_{threshold}$ is presented in (c).



(a) (b) (c)

The MO is identified as voxels with signal intensity lower than $\bar{x}_{intensity} - 2 \cdot \sigma_{intensity}$ in surrounding hyperenhanced myocardium [3]. The direct transfer of these contours to Cine-MR image sequences for their combined evaluation leads to two problems.
Alignment: Cine-MR and DE-MR imaging require different settings. These different settings lead to different field of views or different patient positions. A rigid registration method is applied to align the datasets (Fig. 2).
Correspondence: In the same spatial position one DE-MR and several temporal Cine-MR images exist. Combination of both requires the definition of correspondence. This problem is addressed using Mutual Information [4] as similarity measure. Thus, information of both MR datasets can be combined transferring the contours of the registered DE-MR to the corresponding Cine-MR image sequence. Furthermore all Cine-MR frames of each slice are registered using non-linear demon based registration [5]. Applying the resulting transformation to the corresponding DE-MR slice a moving DE-MR can be computed.
Detailed cardiac analysis requires a high local resolution. Based on the anatomical contours myocardial segments are generated and numbered [6]. Segments of different phases and different patients but with the same segment number can be identified as corresponding. Thereafter local quantitative parameters like size, length and transmurality are computed automatically for each myocardial segment. Combination of end-systolic and end-diastolic contours enables the calculation of parameters characterizing endocardial motion and increase of the wall thickness. Also global parameters e.g. infarct size are calculated.
We implemented HeAT utilizing ITK and VTK with a problem-oriented adaptation.

3 Results

HeAT was evaluated using Cine-MR and DE-MR datasets of six patients (#2−7) after myocardial infarction and one patient (#1) with a healthy heart. Two

Table 1. For datasets #1 – #4 size of HS and IS relative to the myocardial area [%] and $\bar{x} \pm \sigma$ of EM and DT in mid-ventricular slice are represented. Additionally for #7 the results for microvascular obstruction (MO) area are shown

patient	section	[%]	EM[mm]	DT[mm]
#1	HS	$100,0$	$10,0 \pm 2,8$	$5,3 \pm 1,5$
#2	HS	$77,1$	$7,2 \pm 2,1$	$2,7 \pm 1,6$
	IS	$22,9$	$1,9 \pm 1,1$	$1,0 \pm 1,0$
#3	HS	$83,7$	$5,6 \pm 1,9$	$5,6 \pm 2,2$
	IS	$16,3$	$4,5 \pm 0,7$	$3,4 \pm 1,3$
#4	HS	$94,3$	$7,4 \pm 2,2$	$3,7 \pm 2,1$
	IS	$5,7$	$6,4 \pm 0,8$	$3,1 \pm 0,6$
#7	HS	$76,2$	$12,3 \pm 1,9$	$7,4 \pm 1,6$
	IS	$23,8$	$4,1 \pm 2,2$	$3,4 \pm 2,1$
	MO	$2,8$	$2,9 \pm 1,3$	$1,4 \pm 0,9$

physicans defined an apical, a midventricular and a basal slice for each patient and outlined the anatomical and pathological structures. During the analysis the mean $\bar{x}$ and standard deviation σ of endocardial movement (EM) and difference of thickness (DT) of healthy (HS) and infarcted (IS) section were compared (Tab. 1).

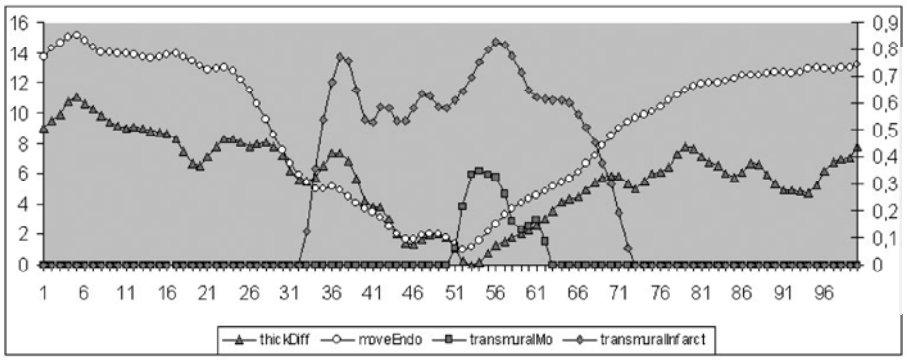
The quantitative parameters of #1 describe the movement of a healthy heart. #2 and #5 reflects the expected degree of myocardial infarction. In the infarction area EM and DT are decreased (5 mm) due to the loss of its contractile function. In contrast, in #3 and #6 the differences of EM are low ($< 1,1$ mm) and the differences of DT are high ($> 2,2$ mm). This result can be interpreted as a passive myocardial contraction. In #4 the changes of EM and DT values are not significant ($< 1,0$ mm). Here, the infarct area is small and heart function is influenced minimally. In #7 MO was discovered. In the basal and mid-ventricular slice the MO values of EM and DT are high decreased and indicate the center of the infarct (Fig. 3).

In apical slice characteristics of passive movement can be observed. The computation of quantitative parameters using HeAT is useful to get objective and observer-independent criteria for the characterization of LV remodeling.

4 Discussion

The automatic parameter extraction and their visualization proofed to be helpful for the evaluation of patient image data after myocardial infarction. The visualization of the analysis results reflect significant changes in shape and motion in the patient data considered. The registration of Cine- and MR image sequences enables the combined analysis of motion and shape in infarct regions and healthy tissue. According to LV remodeling the diagnostic impact of the generated DE-MR sequences at different phases of the heart cycle has to be evaluated in future. The manual segmentation was time-consuming and its re-

Fig. 3. Representation of the quantitative parameters for all myocardial segments. The absolute values mm of endocardial movement (circles) and the difference in wall thickness between end-diastolic and end-systolic phase (triangles) are displayed as well as the transmurality % of the infarct area (diamonds) and the MO (boxes).



sults were user-dependent. Therefore automatic or semi-automatic methods have to be developed to improve the segmentation process. In the next step a database of a population of infarct patients will be established with base-line (acute phase) and follow-up (approx. 6 month past acute) evaluations concerning left ventricular remodeling. This can be useful for predicting the course of disease of an acute infarct patient.

References

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