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Combination of Short- and Longaxis MR Image Sequences for the 3D Segmentation of the Left Ventricle

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Abstract. Segmentation of the left ventricle (LV) is required to quantify LV remodeling after myocardial infarction. Therefore spatiotemporal Cine MR sequences including longaxis and shortaxis images are acquired. In this paper a new segmentation method for fast and robust segmentation of the left ventricle in 4D MR images is presented. The new approach considers the position of the mitral valve and the apex as well as the longaxis contours to generate a 3D LV surface model. The segmentation result can be checked and adjusted in the shortaxis images. Finally quantitative parameters were extracted. For evaluation the LV was segmented in eight datasets of the same subject by two medical experts using a contour drawing tool and the new segmentation tool. The results of both methods were compared concerning robustness and interaction time and intra- and interobserver differences. The presented segmentation method proved to be fast and robust and the intra- and interobserver differences are decreased significantly.

Keywords. Cardiovascular magnetic resonance, Image processing, Left ventricular segmentation

Introduction

Cardiovascular disease is reported as the number one cause of death globally. Approximately 280,000 Germans suffer from a myocardial infarction each year. The infarcted area of the myocardium loses its ability to contract and the remaining healthy muscle needs to compensate for that weakened area. This yields to left ventricle (LV) remodeling which is characterized by e.g. decreased LV ejection fraction. The quantification of LV remodeling based on volume and mass parameters is an indicator for diagnosis and treatment planning. In 2006, Säring et al. presented the software

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system HeAT (Heart Analysis Tool) for the quantitative analysis of 4D MR image sequences [1]. The analysis was based on a manual LV segmentation where the user

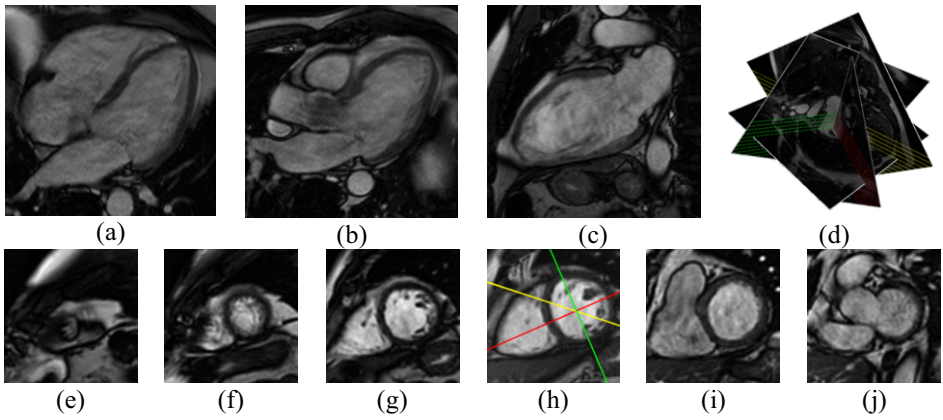


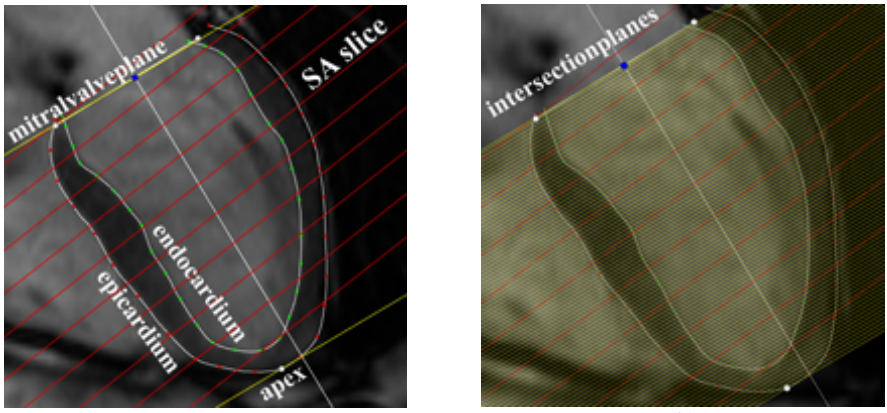
Figure 1. 4D Cine MR sequence: 2D images in 4-chamber longaxis (a), 3-chamber longaxis (b), 2-chamber longaxis (c) and a sequence of shortaxis (e-j) views from the apex to the mitralvalve. Position and orientation of 4-chamber (red), 2-chamber (green) and 3-chamber (yellow) image in a midventricular SA slice (h) and in 3D coordinate system (d).

has to define endocardial and epicardial structures in all shortaxis images. This segmentation process is time-consuming and observer-dependent.

In this paper a new semi-automatic segmentation method for the extraction of the myocardium of the left ventricle combining longaxis (LA) and shortaxis (SA) images is presented. Recently several approaches for the LV segmentation were published. These approaches can be divided into intensity, shape and model based methods [2,3]. Generally these methods operate on shortaxis images (Fig. 1(e-j)) only. Due to the slice thickness of 10mm and the orientation of SA images in clinical Cine MR datasets the definition of the ending (mitral valve) slice is ambiguous, because of different numbers of SA images has a strong influence to the computed volume and mass parameters. Therefore longaxis images in 4-chamber, 3-chamber and 2-chamber view have to be included to identify the position of the mitral valve plane in 3D space (Fig. 1(a+c)). Goshtaby et al. [4] show the fusing of LA and SA images into an isotropic volume image using voxel interpolation without posterior LV segmentation. In van Geuns et al. [5] SA contours are generated based on LA contours using spline interpolation. Here the global parameters are computed using the Simpson rule on the number of SA contours without including information concerning the mitral valve position.

1. Materials and Methods

The goal of this work is to develop a fast and robust segmentation method with reduced inter- and intraobserver variability. Therefore LA information about position and orientation of the mitral valve plane (*MVP*) and the apex as well as the myocardial contours (endocardium, epicardium) are used to generate a 3D surface model of the left ventricle. Due to the fact that only 6 LA contours have to be outlined in our approach the time for the segmentation process will be decreased. After generation the shape of the model can be visually inspected and if needed manually adjusted in SA images.



(a) (b)

Figure 2. Position of the mitral valve plane and SA images (a) and the intersection planes covering the whole LV with a slicethickness of 1mm (b)

1.1. Material

Unfortunately no gold standard for LV segmentation exists and software phantoms are often used to evaluate new methods [6]. In this paper four datasets ($D_{1,2,3,4}$) from the same subject but in different subject positions are acquired. The slice thickness s is changed in comparison to the clinical standard ($D_{1,2}$: s = 6mm, no gap; D_3 : s = 8mm, gap = 2mm; D_4 : s = 10mm, gap = 2mm; standard: s = 8mm, gap = 2mm). Two of these datasets D_k with k = 1; 2 were divided into subdatasets with different numbers of slices, different start slices and different s.

- D^1_k is built by appending all odd numbered slices of D_k
- D^2_k is built by appending all even numbered slices of D_k

In the ideal case the calculated volume and mass parameters for all datasets should be equal. $D_{1,2,3,4}$ are acquired in 4-chamber, 3-chamber and 2-chamber longaxis view (LA) and a sequence of shortaxis (SA) views.

1.2. Methods

In this paper LA and SA images are transferred from 2D in a 3D coordinate system based on the DICOM header information solving a linear equation [4] (Fig. 1(d)).

The mitral valve and the apex as well as endocardial and epicardial contours are outlined in the LA 2D views (Fig. 2(a)). The mitral valve plane (*MVP*) is build in 3D using position information of both LA views. Then intersection planes (ISP_i with $i = 1,...,n$) with a distance of 1mm are generated automatically parallel to the *MVP* covering the whole left ventricle from the apex to the mitral valve (Fig. 2(b)).

For each plane ISP_i the six endocardial $endo^j{}_i$ and six epicardial $epi^j{}_i$ ($j = 1,...,6$) intersection points are calculated (Fig. 2(c)). Defining these intersection points as seedpoints enables the generation of smooth in-plane contours $C^{endo}{}_i$ and $C^{epi}{}_i$ using Bezier interpolation. 3D surface models for endocardium and epicardium are constructed based on LA contours and all in-plane contours $C^{endo}{}_i$ and $C^{epi}{}_i$ for $i = 1,...,n$. Additionally contours in the original shortaxis views are extracted by cutting the surface models in 3D space

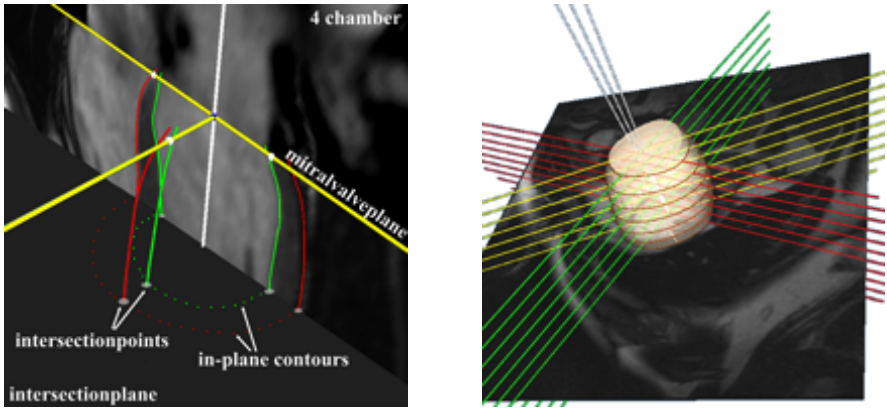


Figure 3. Generation of the in-plane contours based on the intersection points (a) and visualisation of the cutted SA contours. Intersection lines of the SA sequence with the LA images are displayed (b); 4-chamber view: red, 3-chamber view: yellow, 2-chamber view: green

with the image plane. These contours can be reviewed and adjusted. Mass and volume parameters are calculated using the adjusted 3D surface models.

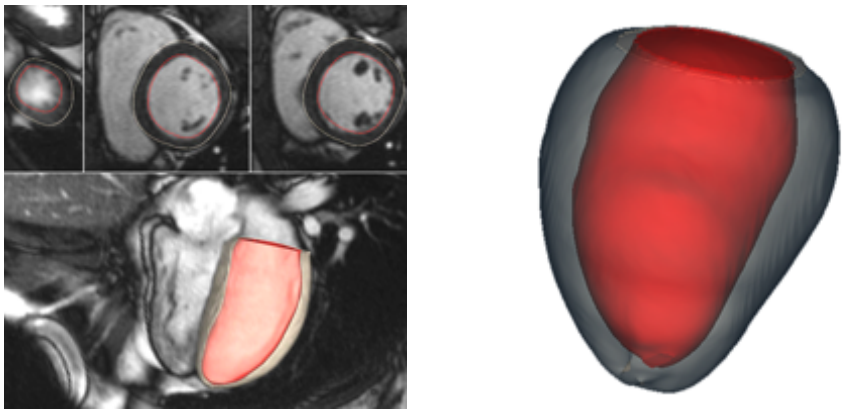
1.3. Evaluation

For evaluation purpose endocardial and epicardial contours of the datasets $D_{1,2,3,4}$ in end-diastolic and end-systolic phase in all shortaxis MR images are outlined by two medical experts ($obs1$, $obs2$) using a contour drawing tool [1]. Each observer traced the contours of each dataset two times with the manual segmentation. Therefore approx. 500 contours have to be defined. Based on these contours five global parameters (e.g. enddiastolic volume (EDV), LV ejection fraction (LVEF)) were extracted for each dataset using the Simpson rule. Then the presented segmentation method is used to compute the same global parameters including LA information. For each dataset only 6 LA contours need to be defined. If needed the shape of the generated model is manually adjusted. Then two comparison sets were obtained, each based on the eight datasets $D_{1,2,3,4}$ and $D^{1,2}{}_k$ with $k = 1,2$: measurements obtained by $obs1$ the first time versus the second time (Intraobserver variability) and the averaged difference of measurements obtained by observer $obs1$ the first time versus $obs2$ and those obtained by $obs1$ the second time versus $obs2$ (interobserver variability). Furthermore the influence of the different slice thickness (s = 6; 8; 10; 12mm) of the MR datasets of the same subject to the extracted parameters

2. Results

Four 4D Cine MR image sequences were obtained at the Department of Diagnostic and Interventional Radiology from one subject in different positions using a Siemens 1.5T MR scanner. Longaxis and shortaxis images were acquired by using

electrocardiographically triggered breath-hold imaging techniques according to the American Heart Association (AHA) scientific statement. For each slice 20 phases



(a) (b)

Figure 4. Result of the segmentation process: Contours of the surface overlayed in SA slices and 4-chamber view (a). Final surface model of the left ventricle in diastolic phase (b)

provided the complete coverage of the cardiac cycle resulting in a total of 380 cardiac images per sequence. The inter- and intraobserver differences comparison between global LV function for manually and semi-automatically segmented images are shown in Tab. 1+2. The mean and standard deviation of the differences in [*ml*] and [%] of all parameters is decreased. In case of intraobserver comparison e.g. the mean EDV difference between first time and second time of *obs*1 is reduced from *13.7%* to *2.3%*. Concerning slice thickness the mean differences of EDV (*14.1%* to *5.8%*) and ESV (*18.8%* to *4.9%*) are decreased but SV (*10.7%* to *20.7%*) and LVEF (*4.3%* to *11.6%*) are increased.

Table 1. Intraobserver difference comparison of *obs*1 between global LV function for manually and semi automatically segmented images [mean difference ± std]. (EDV: end-diastolic volume; ESV: end-systolic volume; SV: stroke volume; LVEF: left ventricular ejection fraction; Mass: mass of the myocardium)

	manual		semi-automatic	
	absolute	relative	absolute	relative
EDV [ml]	6.4 ± 0.5	4.5 ± 0.8	1.7 ± 0.1	1.3 ± 0.0
ESV [ml]	5.9 ± 7.5	8.8 ± 11.2	0.3 ± 0.2	0.5 ± 0.3
SV [ml]	5.5 ± 1.6	7.3 ± 1.1	2.9 ± 0.6	4.0 ± 0.3
LVEF [%]	4.2 ± 2.7	7.6 ± 4.5	1.5 ± 2.6	0.8 ± 1.2
Mass [g]	7.8 ± 5.3	7.5 ± 4.7	6.2 ± 6.1	4.8 ± 4.7

3. Discussion

A semi-automatic LV segmentation method has been developed that combines LA information and intersection planes as well as SA images. In the presented work global parameters including position and orientation of the mitral valve and the apex are extracted. The generation of intersection planes and in-plane contours covering the

whole left ventricle enable the construction of a surface model (Fig. 3(a+b)) and its quantitative analysis. The inter- and intraobserver differences can be decreased for all extracted parameters. Using the presented approach the time needed for the segmentation process is decreased from 60 minutes to 5 minutes including manual adjustment. So the semi-automatic segmentation using LA information proved to be fast and robust for the quantification of LV mass and volume properties. Currently the presented segmentation tool is used to evaluate LV remodeling based on 4D Cine MR

Table 2. Interobserver difference (*obs1 – obs2)* comparison between global LV function for manually and semi-automatically segmented images [mean difference ± std]

	manual		semi-automatic	
	absolute	relative	absolute	relative
EDV [ml]	17.8 ± 11.7	13.7 ± 9.5	2.9 ± 2.1	2.3 ± 1.7
ESV [ml]	7.9 ± 8.0	11.3 ± 11.6	3.1 ± 2.0	4.9 ± 3.1
SV [ml]	13.0 ± 13.4	22.7 ± 25.9	5.6 ± 6.1	9.1 ± 2.6
LVEF [%]	9.4 ± 2.7	20.9 ± 8.2	3.1 ± 4.1	6.3 ± 8.4
Mass [g]	15.5 ± 13.7	6.3 ± 5.0	1.1 ± 0.8	0.6 ± 0.5

datasets of thirty patients with myocardial infarction in a baseline (acute infarction phase) vs. follow-up (approx. 15 month later) study. In future the variability concerning slice thickness has to be evaluated. Also the influence of papillary muscles and trabecular structures has to be analyzed to improve the quality of the extracted global parameters. Automatic adaptation of the contours to all time points will enable the generation of a 4D heart model to visualize dysfunctional areas of the left ventricle.

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