Three dimensional Time Resolved Segmentation of the Left Ventricle

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Background: Segmentation of the left ventricle (LV) is of great interest since it directly gives important clinical parameters such as end-diastolic volume (EDV), end-systolic volumes (ESV), ejection fraction (EF), left ventricular mass (LVM) etc. Earlier methods for segmenting the left ventricle have used a wide range of techniques such as level sets [1], probabilistic models [2], active appearance models [3]. Active appearance and probabilistic models have problems with data sets that lie outside the learning material, and level set methods have difficulty including enough a priori information to make them robust.

Method: We propose a segmentation algorithm based on the concept of deformable models, but extended with an enhanced and fast edge detection scheme that includes temporal information and anatomical a priori information. The algorithm takes a stack of time resolved short axis images and performs the segmentation simultaneously within the time-resolved 3D volume, in order to utilize as much of the available image data as possible. The model is initialized as a 'cone' in the left ventricle and is allowed to expand and deform towards the endocardial surface. In the deformable model the used forces are an inflation balloon force, an edge force, a curvature force, a slice force, damping and acceleration forces, and a user interaction force. To enable wall motion studies the papillary muscles are excluded. This is achieved after a coarse segmentation and fitting of an approximately circular shape to the extracted contour. The final position of the contour is subsequently found after a few additional iterations using the deformable model. The mass/volume of the papillary muscles is excluded from the LV volume calculations, but included in the LVM calculation. This is done by detecting the papillary muscles within the blood pool using an automatically calculated threshold. The epicardial segmentation is initiated at and coupled to the endocardial surface. LV long-axis motion is included in the volume calculation by manually measuring the long-axis motion in separately acquired long-axis images. Fractions of the most basal slice(s) are removed as a function of the volume curve. The proposed method is implemented into a cardiac analysis software package freely available for research at http://www.cmiv.liu.se/software.

Results: The method is validated on 14 MRI-SSFP data sets (mixed patient population acquired using a Philips Intera scanner), and 9 MRI gradient echo data sets (healthy volunteers acquired on a Siemens Magnetom Vision scanner). Comparison with manual segmentation is shown in Figure 1. The basal slices are the most difficult to segment and there the average volume error was 37% compared to the overall error that was 3%. The time to perform necessary manual corrections (in all timeframes) is approximately 2-3 minutes depending on data quality. The total computational time for segmentation is 40s on a 1.4GHz Intel Pentium 4 PC for an average data set with 12 slices and 30 timeframes. This should be compared to the time for manual segmentation of two time frames that took 25±5 minutes for the used data sets.

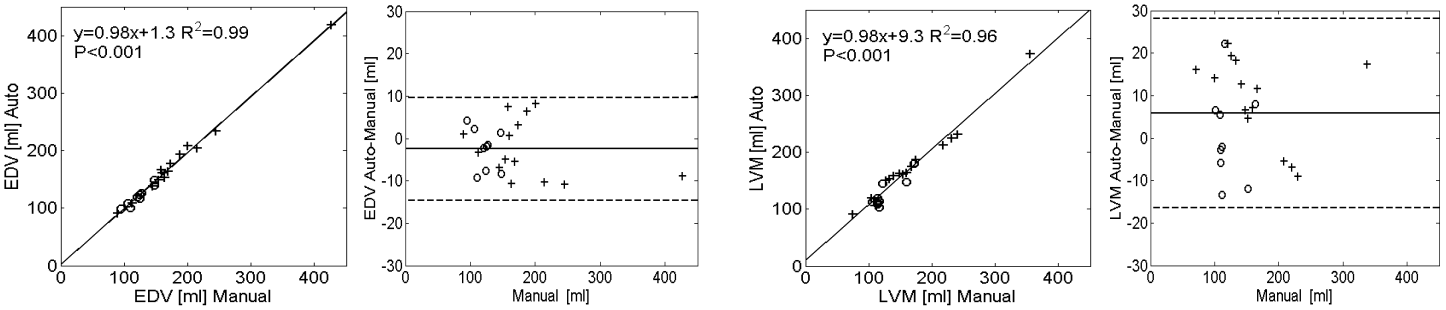

Figure 1. Correlation and Bland-Altman plots comparing the results from manual and automated segmentation. Left: End-diastolic volume (EDV). Right left ventricular mass (LVM). Circles denotes MRI-gradient echo images, and + denotes MRI-SSFP.

Conclusions: The automated segmentation gives a segmentation for all timeframes that enables studies of inflow patterns and quantification of peak filling/ejection rate. The automated segmentation combined with a few user interactions provides a significant time saving with a factor of approximately five compared to manual segmentation.

References:

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