Cardiac image segmentation using Level Sets with Preserved Topology

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INTRODUCTION: Many cardiac performance measures are estimated from the computation of ventricular volumes. This is usually assessed using Simpson's rule applied over image segmentations of ventricles obtained from Short Axis (SA) cine MRI scans of the heart. Segmentations are usually performed manually, which is tedious, time consuming and has a high intra and inter observer variability. Level Sets-based algorithms have been used to perform automatic and faster segmentations [1, 2]. Due to the presence of multiple objects (Fig 1), noise and artifacts in the images, Level-Sets needs to be guided or restricted. One alternative has been the use of shape priors [1, 2], i.e. Level Set templates that are allowed to be deformed, but in a restricted way, which is defined during a training process. Those training processes are not straightforward, since they normally require several training examples and some degree of human intervention. Furthermore, methods based on training data tend to fail with severely abnormal shaped hearts.

We propose the use of Level Sets with Preserved Topology (LSPT). This approach adds a local constraint to the deforming Level Sets, so that they always preserve their topological properties. These properties are defined during the curve initialization, without any extra human interaction. Importantly, the main advantage of the method is that no training data set is needed.

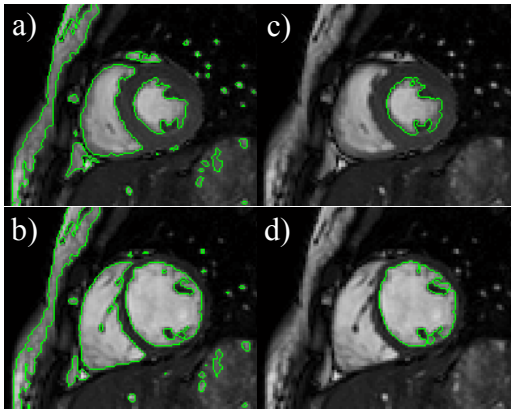

Figure 1: Level Sets without preserved topology segments multiple objects in the image at end systole (a) and end diastole (b). Alternatively, LSPT restricts the segmentation to a specific object with known topology at end systole (c) and end diastole (d).

METHODS: We implemented a standard Level Sets algorithm, 2D Active Contour Without Edges (ACWE) [3], but we forced the deforming Level Sets to preserve their initial topology. That is, to allow any deformation, except those that produce curve splitting, merging, or any other topological change. The topological preservation was automatically achieved including a local constraint to each pixel of the deforming Level Set, as described in [4].

The segmentation algorithm was initialized with a simple contour, typically an ellipse, so that the human intervention was minimal. The ACWE parameters [3] were: $\mu = 0.004\times255^2$; $\lambda_1 = 1.2$; $\lambda_2 = 0.8$; $\Delta t = 0.00002$; re-initialization of □ every 90 iterations; stopping condition 800 iterations. The parameters for the topology preservation [4] were: foreground connectivity = 8 and background connectivity = 4.

We evaluated the accuracy of our proposed method through the segmentation of the left ventricle from nine cardiac b-SSFP SA cine MRI scans: two healthy volunteers and seven patients with different heart diseases (e.g. stenosis and regurgitation of the atrio ventricular and semilunar valves, post tetralogy of Fallot repair). The acquisition parameters were: spatial resolution of 1.6mm^2; slice thickness of 8mm; and temporal resolution of 30ms. Scans were segmented at two cardiac phases (end systole and end diastole). End Systolic Volume (ESV), End Diastolic Volume (EDV), and Stroke Volume (SV) computed from the LSPT segmentations were compared with those obtained from manual segmentations. To evaluate intra-observer reproducibility, manual and LSPT segmentations were performed twice in a blind fashion (one operator performing the two manual segmentations and a different operator performing the LSPT ones). Manual segmentations were done using a commercially available software (Viewforum, Philips Healthcare).We assessed the agreement between measurements using the Bland Altman and T-test analyzes.

RESULTS: All data sets were successfully segmented with the proposed method (Fig 1 c and d). Bland Altman and T-test showed equivalent results for the left ventricle ESV, EDV, and VS comparing manual and LSPT methods (Fig 2 and Table I). The LSPT method had a better intra-observer reproducibility than the manual segmentation, as shown by the smaller mean and range in the Bland Altman test (Table I).

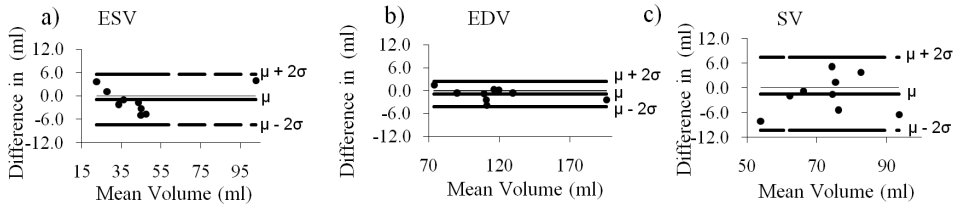

Figure 2: Comparison of ESV (a), EDV (b), and SV (c) between the manual and LSPT segmentations. The parameter μ and σ correspond to the mean and standard deviation of the differences between manual and LSTP calculations, respectively.

Table I: Intra observer measurements.

	Mean	Range	t-test	Correlation
Intra manual ESV	-3.29	[-13.81; 7.24]	0.10	0.97
Intra LSPT ESV	0.42	[-1.30; 2.13]	0.19	0.99
Intra manual EDV	-0.71	[-9.96; 8.54]	0.66	0.99
Intra LSPT EDV	0.74	[-2.19; 3.67]	0.39	0.99
Intra manual SV	2.57	[-13.61; 18.76]	0.38	0.75
Intra LSPT SV	0.32	[-3.75; 4.39]	0.66	0.99

CONCLUSION: LSPT allowed us to segment accurately and reproducibly the left ventricle with minimal human intervention. The main advantages of the method are that it does not required any training data and it can be applied to abnormally shaped heart, such as in some patient with congenital heart diseases.

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