3-D LGE-MRI Segmentation using a Random Forest Classifier and Dynamic Programming

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Introduction: Ischemic heart disease is the leading cause of death (1). State-of-the-art is 2-D LGE-MRI to visualize myocardial scar, however, incomplete coverage doesn't allow to compute the total scar burden. Therefore, an isotropic high resolution 3-D whole heart LGE-MRI was proposed (2). The challenge lies in the delineation of the myocardium. We developed a method for automatic left ventricle (LV) segmentation in 3-D LGE-MRI based on random forest (RF) classification and dynamic programming as pre-requisite for scar quantification.

Methods: The segmentation of the LV consists of five steps. First, the LV is initialized using a two-stage registration (Figure1B) (3). Second, the short axis view is estimated using principal component analysis (Figure1C). Third, the endocardium is estimated using a RF classifier, which is trained using 16 steerable features (4). Potential boundary points are extracted using circular ray casting (Figure2A). The classification result is interpreted as boundary costs (Figure3A). To improve the endocardial segmentation, a scar exclusion is added. Therefore, the mean intensity μ_{bp} and standard deviation σ_{bp} of the blood pool are estimated. The scar threshold θ_s is defined as $\theta_s = \mu_{bp} + \sigma_{bp}$ (Figure3B). A scar map is generated, where all pixels with increasing radius from potential scar candidates are labeled with 1 (Figure3C). The scar map is combined with the boundary map, resulting in a cost map (Figure3D). The shortest path in polar space is found using a minimal cost path (MCP) (Figure3E). The contour is transformed back to Cartesian coordinates and the convex hull is obtained (Figure4A,B). These steps are repeated for every slice, until base and apex are reached. Afterwards, the epicardial boundary is estimated using the RF classifier for the epicardium and the MCP (Figure 4C). In the final step, the myocardium contour can be exported and used for scar segmentation.
The segmentation was evaluated using 9 LGE-MRI data sets (sparse GRE sequence and reconstruction, spatial resolution $(1.3\ mm)^3$). A comparison to gold standard annotations from two clinical experts using a leave-one-out cross-validation was performed.

Results and Discussion: The segmentation resulted in a Dice coefficient of 0.84±0.07 for the endocardium and 0.85±0.05 for the epicardium. The biggest differences occur at the left ventricular outflow tract. Incorporating a heart model might further improve the segmentation.

Conclusion:
The presented work segments the LV solely using LGE-MR. It has been shown that a trained RF classifier for the endocardium and epicardium combined with a MCP can lead to good LV segmentation results, as a prerequisite for scar quantification.

Disclaimer: The methods and information presented are based on research and not commercially available.

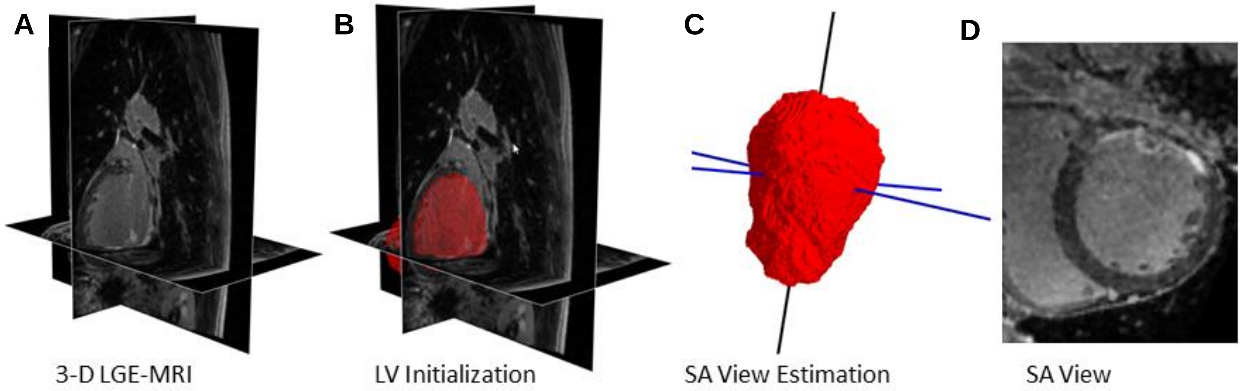

Figure 1: A) 3-D LGE-MRI volume. B) Left ventricle is initialized using a two-step registration approach. C) Principal axes of the left ventricle are estimated. D) Estimates short axis view by rotating the volume around the first principal component.

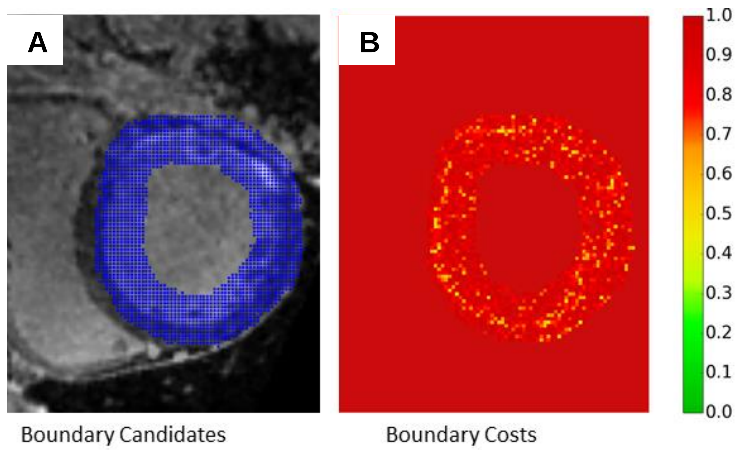

Figure 2: A) Possible endocardial boundary candidates. B) Estimated boundary costs after random forest classification.

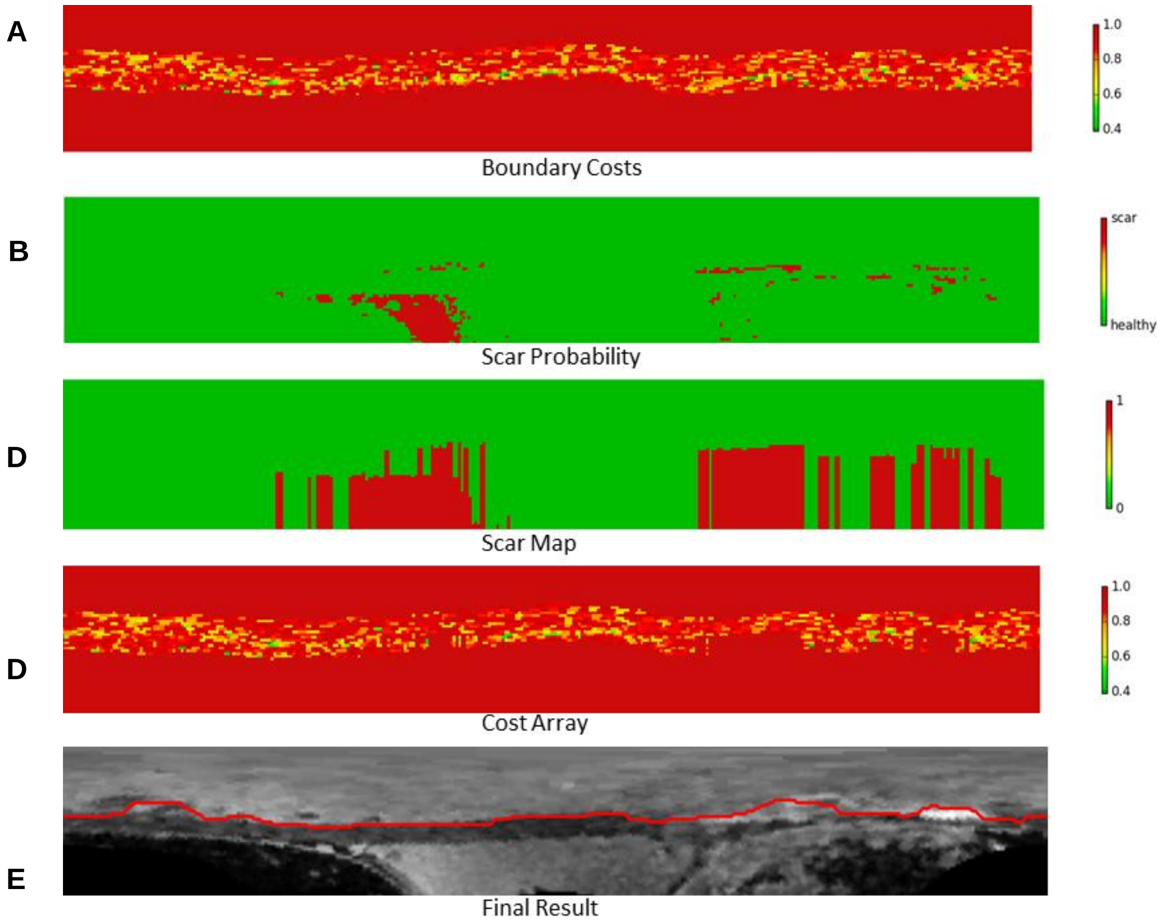

Figure 3: A) Boundary costs in polar space. B) Scar probability. C) Scar map. D) Cost array which is a combination of the boundary costs and the scar map. E) Final result of the minimal cost path search.

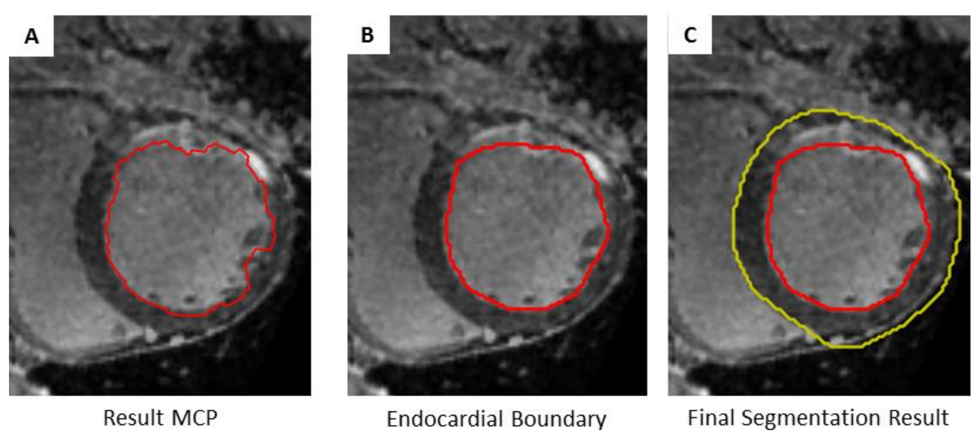

Figure 4: A) Result of the minimal cost path search after conversion to Cartesian coordinates. B) Final result of the endocardial contour after taking the convex hull. C) Final result of the endocardial (red) and epicardial contour (yellow).

References

1. **Nichols, Melanie and Townsend, Nick and Scarborough, Peter and Rayner, Mike.** Cardiovascular disease in Europe: epidemiological update. January 2013, Vol. 34, 39.

2. **Hu, T. Shin and M. Lustig and D. Nishimura and B.** Rapid single-breath-hold 3D late gadolinium enhancement cardiac MRI using a stack-of-spirals acquisition. *Journal of Magnetic Resonance Imaging.* 40, 2014, Vol. 6.

3. **Tanja Kurzendorfer, Christoph Forman, Michaela Schmidt, Christoph Tillmanns, Andreas Maier and Alexander Brost.** Fully Automatic Segmentation and Scar Quantification of the Left Ventricle in 3-D Late Gadolinium Enhanced MRI. *11th Interventional MRI Symposium.* 2016.

4. **Zheng, Yefeng and Barbu, Adrian and Georgescu, Bogdan and Scheuering, Michael and Comaniciu, Dorin.** Four-chamber heart modeling and automatic segmentation for 3-D cardiac CT volumes using marginal space learning and steerable features. *IEEE transactions on medical imaging.* 27, 2008, Vol. 11.

5. **Karim, Rashed and Bhagirath, Pranav and Claus, Piet and Housden, R James and Chen, Zhong and Karimaghaloo, Zahra and Sohn, Hyon-Mok and Rodríguez, Laura Lara and Vera, Sergio and Albà, Xènia and others.** Evaluation of state-of-the-art segmentation algorithms for left ventricle infarct from late Gadolinium enhancement MR images. 2016, Vol. 30.