Automatic Layer Generation for Scar Transmurality Visualization

S. Reiml[1,4], T. Kurzendorfer[1,4], D. Toth[2,5], P. Mountney[6], M. Panayiotou[2], J. M. Behar[2,3], C. A. Rinaldi[2,3], K. Rhode[2], A. Maier[1] and A. Brost[4]

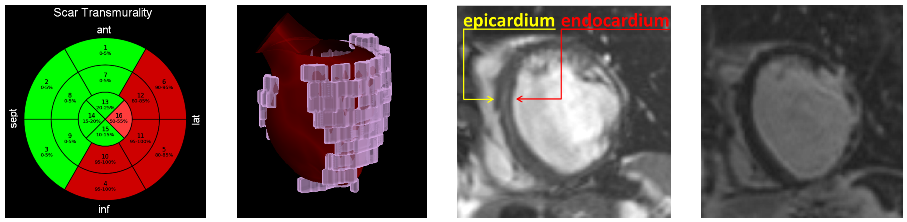
[1] Pattern Recognition Lab, Friedrich-Alexander-University Erlangen-Nuremberg, Germany
[2] Department of Biomedical Engineering, King's College London, United Kingdom
[3] Department of Cardiology, Guy's and St. Thomas' NHS Foundation Trust
[4] Siemens Healthcare GmbH, Forchheim, Germany
[5] Siemens Healthcare Ltd, London, United Kingdom
[6] Medical Imaging Technologies, Siemens Healthcare, Princeton, NJ
sabrina.reiml@fau.de

Abstract. In 2014, about 26 million people were suffering from heart failure. Symptomatic heart failure is treated by cardiac resynchronization therapy. However, 30 % to 50 % do not clinically respond after the implantation of a biventricular pacemaker. To improve the success rate, the quantification of a patient's scar burden is very important. Late-gadolinium-enhanced magnetic resonance imaging is used to visualize regions of scarring in the left ventricle. Scar is very hard to visualize and interpret in 3-D. To solve this, an automated scar layer generation method is proposed. The scar is divided into layers and an interactive scrolling is provided. This method allows for precise treatment planning. With the scar layer visualization, eight clinical experts were asked to decide if the scar is epicardial or endocardial. The correct location was identified in 93.75 % of the cases using the scar layer visualization.

1 Introduction

Heart failure affected in 2014 about 26 million people worldwide [1]. Symptomatic heart failure is often treated by cardiac resynchronization therapy (CRT). Patients eligible for CRT undergo a minimally invasive procedure for implantation of a biventricular pacemaker, often called CRT device [2].

The localisation and quantification of scar tissue in the myocardium of the left ventricle (LV) is crucial to increase the success rate of CRT [3, 4]. However, the myocardial scar distribution can be challenging to interpret, in particular the transmurality. Transmurality is present when the scar extends from the endocardium to the epicardium. The problem in CRT is that about 30 % to 50 % of the patients do not respond clinically [5]. One of the main reasons of non response is considered to be suboptimal placement of the left ventricular pacing lead. Pacing in areas of myocardial infarction has less effect, because scar tissue is not electrical conductive. To improve the success rate, precise scar information is required for choosing the optimal pacing location.



(a) (b) (c) (d)

Fig. 1. (a) 2-D visualization of the scar transmurality in a bull's eye plot. (b) 3-D mesh visualization with the left ventricle's endocardium (dark red) and the 3-D scar distribution (light purple). (c) 2-D short axis Cine image of the LV for anatomy segmentation. (d) 2-D short axis LGE image of the LV for scar tissue quantification.

The state-of-the-art for assessing the viability of the myocardium is late-gadolinium-enhanced magnetic resonance imaging (LGE-MRI). The anatomy is segmented from Cine MRIs, where the contours of the myocardium are more clearly visible compared to the LGE-MRI scan [6]. Most methods available consider a semi-automatic approach for scar segmentation [7, 9].

Currently, there are two methods for the visualization of scar transmurality. The first method is the mapping of scar information to a so-called bull's eye plot (BEP), as shown Fig. 1 (a). Scar transmurality is presented as percentage for each segment of the BEP. The drawbacks of this approach are the non-anatomical visualization of the LV as a BEP and the missing information about the scar's location within the myocardium. Furthermore, no 3-D guidance is possible. The second method is to visualize the scar as a 3-D mesh, see Fig. 1 (b). The advantage of this approach is the 3-D anatomical visualization. The disadvantage of this method is that there is no information about scar transmurality.

While Reiml et al. showed different scar visualization methods [8], in this work a novel method for 3-D scar layer generation is presented. We propose an interactive 3-D scar location and transmurality visualization method.

2 Scar Layer Generation

In this section, the interactive visualization technique for 3-D scar transmurality is described. The main method consists of five steps, as depicted in Fig. 2.

MRI Segmentation: In the first step, the endocardium and epicardium are segmented from anatomical MRI scans. After the delineation of the myocardium, the anatomical scan is registered to the LGE-MRI, which is used for the segmentation of the scar tissue [7]. This tissue is segmented using a semi automatic approach [9]. Examples of Cine MRI and LGE-MRI are depicted in Fig. 1(c, d). The output of the segmentation is a mask containing the blood pool, the myocardium and the information about the myocardial scar, see Fig. 2 second box for a single slice.

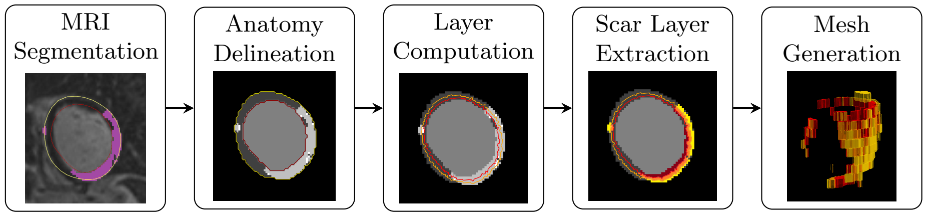


Fig. 2. Overview of the five steps for the 3-D scar location and transmurality visualization. First, the left ventricle and the scar are segmented. Second, the epicardium and endocardium are delineated. Third, the layers are computed. Fourth, the scar layers are extracted. In the last step, the scar layer meshes are generated.

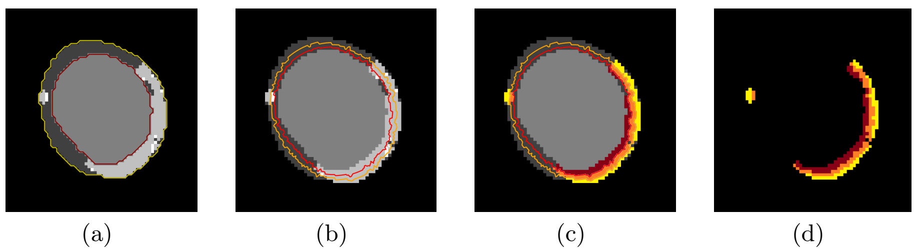


Fig. 3. Scar layer generation process illustrated in one slice. (a) Segmentation mask with detected epicardium (yellow) and endocardium (red). The blood pool is located inside of the endocardium and the myocardium is between the endocardium and epicardium. Within the myocardium, the scar is shown in a lighter shade of gray and white. (b) Calculated layers. (c) Scar layers. (d) Scar layer masks.

Anatomy Delineation: In the second step, the epicardium and the endocardium are extracted from each of the slices of the segmentation mask. The extraction is based on the marching squares algorithm, which finds the iso-surfaces in the segmentation mask [10]. The epicardial contour (yellow) and the endocardial contour (red) are visualized in Fig. 3 (a).

Layer Computation: In the third step, the segmentation mask, as well as the endocardial and epicardial contour points are transformed into polar space (r, ρ) where r is the radius and ρ the angle, see Fig. 4. Due to Cartesian coordinates (x, y), there are more epicardial points than endocardial points. Hence, it is more difficult to divide the area between the endocardium and the epicardium in multiple layers. There are several advantages using polar coordinates instead of Cartesian coordinates. The epicardium and endocardium in Cartesian coordinates are roughly circular but do not have the same perimeter. In polar space, the transformed epicardium and endocardium outlines have the same length and run almost in parallel, see Fig. 4. Afterwards, the endocardial and epicardial contour points are interpolated. From the interpolated contours, the layers between the endocardium and epicardium are computed, as depicted in Fig. 4. The distance between the endocardium and the epicardium is calculated and then divided into multiple layers. For n layers, the myocardium needs to be divided $m = n - 1$

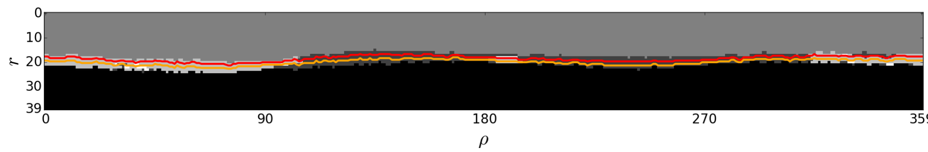


Fig. 4. Transformed mask image into polar space with computed layers (red and orange) between the endocardium and epicardium.

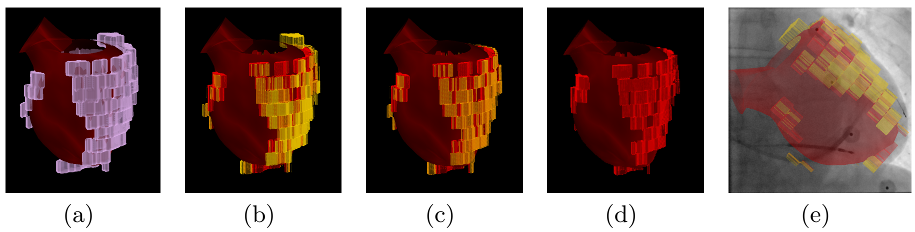


Fig. 5. (a) Endocardium (dark red) with one scar mesh in purple. (b) Endocardium with three scar layers. (c) Endocardium with two scar layers. (d) Endocardium with one scar layer. (e) Fluoroscopic image with overlaid endocardium and 3-D scar layers.

times. For each angle ρ, m values within the myocardium are calculated. After the delineation of the n layers in polar space, they are transformed back to Cartesian coordinates, see Fig. 3 (b-d). In this work, the number of layers is set to three. For the placement of the lead, it is useful to have an epicardial, a mid-myocardial and an endocardial layer to decide where the scar is located.

Scar Layer Extraction: In the fourth step, the previously defined layers and the scar mask are compared using logical operations. For three scar layers, the myocardium was divided twice, as depicted in Fig. 3 (b). The first defined line is next to the endocardium and the second defined line is close to the epicardium. The first filled layer L_1 is defined as the area within the first subdivision layer. The second filled layer L_2 is defined as the area within the second subdivision line. The third layer L_3 is the area within the epicardium. Then the filled layers are logically compared with the scar mask S and the three individual scar layer masks S_1, S_2 and S_3, where $S_1 = L_1 \wedge S$, $S_2 = \overline{L_1} \wedge L_2 \wedge S$ and $S_3 = \overline{L_1} \wedge \overline{L_2} \wedge L_3 \wedge S$ are obtained. The result is depicted in Fig. 3 (c, d).

Mesh Generation: The final step is to extend the 3-D scar mask with the slice thickness, as just a limited number of slices are available. The scar contours are extracted as 3-D surface meshes using the marching cubes algorithm [10]. The image coordinates are transformed to patient coordinates to position the scar layers at the same position as the original scar mesh, see Fig. 5 for an example.

3 Visualization

In this section, two visualization methods are proposed.

Interactive Scrolling: The subdivision of the scar mesh into several scar layers enables an interactive peeling of the scar in 3-D. It can be scrolled from epicardium to endocardium and vice versa as depicted in Fig. 5 (b-d). The interactive adding and removing of the scar layers allows for a good localization, where the scar starts and ends, as well as an assessment of transmurality. If the scar is fully transmural, all scar layers are add up.

Overlay: The 3-D scar layers can be overlaid onto fluoroscopic images, as depicted in Fig. 5 (d). This visualization method can be used during the intervention. For the overlay, the epicardial mesh of the LV is registered to the fluoroscopic image. Then, the epicardium, the endocardium, the scar mesh and the scar layers can be visualized in different colors. The colors and opacity can be adapted manually. Meshes, which the physician is not interested in, can be hidden. This supports the physician during the intervention, as only the required and important information is visible.

4 Evaluation and Results

The scar layer visualization was evaluated using seven clinical data sets, acquired with a Siemens MAGNETOM Aera 1.5T scanner (Siemens Healthcare GmbH, Erlangen). For the evaluation, two tests are created. In the first test, nine physicians are shown four cases. For each case, two visualization methods are presented: the segmented LV overlaid with the 3-D scar mesh and the segmented LV overlaid with the scar layer visualization. They are asked to decide which visualization method they would prefer. In 80.55 % cases, the clinical experts prefer the scar layer visualization, in 16.67 % cases they prefer the 3-D scar mesh and in 2.78 % cases they do not have a preference.

In the second test, eight physicians are shown six 3-D scar meshes and six scar layer meshes. For each visualization method, they should decide if the scar is epicardial or endocardial. The results are shown in Table 1. These two experiments show, that with the scar layer visualization, the clinicians can easily choose an optimal lead placement location as they can decide whether the scar is epicardial or endocardial.

5 Discussion and Conclusion

In this paper, a novel method for interactive visualization of the scar information is presented. In CRT, the lead of the electrode is commonly placed on the epicardium. Precise information about the location and transmurality of the scar is needed, as it is electrically almost non-conductive. The results show that the clinicians could easier decide about the scar location. The precise control over how the scar transmurality is visualized in 3-D allows the user to see the scar location to the extent of transmurality. An interactive scrolling through scar layers is realized, such that scar layers are added or removed from the visualization. The epicardium and the scar meshes can be further overlaid onto fluoroscopic images. The overlay of the meshes can be used to guide an intervention.

	3-D Scar Mesh	Scar Layer Meshes
Correct	18.75 %	93.75 %
Wrong	6.25 %	6.25 %
No Determination	75.00 %	0.00 %

Table 1. Evaluation with eight clinical experts and twelve scar meshes. They should decide for each mesh if the scar is epicardial, endocardial or they could not determine.

Acknowledgements and Disclaimer: The authors are grateful for the support from the Innovate UK grant 32684-234174. The research was supported by the National Institute for Health Research (NIHR) Biomedical Research Centre based at Guy's and St. Thomas' NHS Foundation Trust and King's College London. The views expressed are those of the authors and not necessarily those of the NHS, NIHR or the Department of Health. Concepts and information presented are based on research and are not commercially available.

References

1. Ponikowski P, Anker SD, AlHabib KF, Cowie MR, Force TL, Hu S, et al. Heart failure: preventing disease and death worldwide. ESC Heart Failure. 2014 sep;1(1):4–25.
2. Shea JB, Sweeney MO. Cardiac Resynchronization Therapy A Patient 's Guide. Circulation. 2003 sep;108(9):64–66.
3. Kurzendorfer T, Brost A, Forman C, Schmidt M, Tillmanns C, Hornegger J. Semi-Automatic Segmentation and Scar Quantification of the Left Ventricle in 3-D Late Gadolinium Enhanced MRI. In: 32nd Annual Scientific Meeting of the ESMRMB; 2015. p. 318–319.
4. Cochet H, Denis A, Ploux S, Lumens J, Amraoui S, Derval N, et al. Pre-and Intra-Procedural Predictors of Reverse Remodeling After Cardiac Resynchronization Therapy: An MRI Study. Journal of Cardiovascular Electrophysiology. 2013 jun;24(6):682–691.
5. Daubert JC, Saxon L, Adamson PB, Auricchio A, Berger RD, Beshai JF, et al. 2012 EHRA/HRS expert consensus statement on cardiac resynchronization therapy in heart failure: implant and follow-up recommendations and management. Europace. 2012 jun;14(9):1236–1286.
6. Tao Q, Piers SR, Lamb HJ, van der Geest RJ. Automated Left Ventricle Segmentation in Late Gadolinium-Enhanced MRI for Objective Myocardial Scar Assessment. Journal of Magnetic Resonance Imaging. 2014 nov;42(2):390–399.
7. Jolly MP, Xue H, Grady L, Guehring J. Combining Registration and Minimum Surfaces for the Segmentation of the Left Ventricle in Cardiac Cine MR Images. In: Medical Image Computing and Computer-Assisted Intervention–MICCAI 2009. Springer; 2009. p. 910–918.
8. Reiml S, Toth D, Panayiotou M, Fahn B, Karim R, Behar JM, et al. Interactive Visualization for Scar Transmurality in Cardiac Resynchronization Therapy. In: SPIE Medical Imaging. vol. 9786; 2016. p. 97862S–97862S–8.
9. Karim R, Bhagirath P, Claus P, Housden RJ, Chen Z, Karimaghaloo Z, et al. Evaluation of state-of-the-art segmentation algorithms for left ventricle infarct from late Gadolinium enhancement MR images. Medical Image Analysis. 2016 may;30:95–107.
10. Lorensen W, Cline H. Marching Cubes: A High Resolution 3D Surface Construction Algorithm. CM Siggraph Computer Graphics. 1987 jul;21:163–169.