Automatic Quantification of Cardiac Scar Extent from Late Gadolinium Enhancement Magnetic Resonance Imaging

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Abstract

Late gadolinium enhancement cardiac magnetic resonance imaging (LGE-CMRI) is the technique of choice to detect myocardial scars and assess myocardial viability. In clinical practice, this analysis is performed qualitatively or by manually tracing the enhanced area in each acquired slice. The purpose of this study was to test and validate a technique for automated localization and quantification of scar extent. CMRI data in patients with previous myocardial infarction were analyzed using custom software from which the myocardium was automatically identified from steady-state free precession images and registered on LGE-CMRI data. Scar tissue was defined as myocardium with signal intensity ≥ 80% of its maximum and quantified on each slice. Scar location and extent were assessed and compared with expert analysis. Preliminary results showed that automatic localization of scar from LGE-CMRI is feasible and scar quantification is accurate and reliable.

1. Introduction

As indicated in the ACCF/ACR/AHA/NASCI/SCMR 2010 expert consensus document on cardiovascular magnetic resonance [1], late gadolinium enhancement cardiac magnetic resonance imaging (LGE-CMRI) should be used for identifying the location and extent of myocardial necrosis in individuals suspected of having or diagnosed of chronic or acute ischemic heart disease.

This imaging technique provides a noninvasive mechanism to predict recovery of function after revascularization being able to identify subendocardial or transmural infarctions. In particular, the presence and the transmurality of scar can be quantified and viable myocardium defined as dysfunctional and nonscared tissue. Several studies showed the transmural extent of scars predicts the likelihood of recovery of regional function, and when >20% of the myocardium is hibernating, improvement of ejection fraction is likely [2]. LGE-CMRI may also show nontransmural scars that fail to recover function after adequate revascularization. Overall, LGE CMRI has a negative predictive value of ~90% of no functional recovery in segments with >50% transmural infarction and a positive predictive value of ~80% of recovery in segments without infarction [2].

In addition, recent studies showed LGE-CMRI may be a valuable tool for predicting major adverse cardiac events and cardiac mortality [3].

In clinical practice, scar assessment is performed qualitatively, or based on time-consuming manual tracing of the enhanced area in each acquired slice [4]. This qualitative analysis can be subjective, which limits direct comparison of results between sequential studies and might hinder its clinical application.

Therefore, the purpose of this study was to test and validate a technique for automated endocardial and epicardial border detection and quantification of scar location and extent.

2. Methods

2.1. CMR imaging and population

CMRI data were acquired (Siemens, Avanto, 1.5T) at the Southampton University Hospital NHS Trust, UK, in 5 patients (3 males; age 59±19 yrs) with previous myocardial infarction.

Scout images were acquired first, for identification of the cardiac axes. Dynamic image loops were then acquired perpendicular to the LV long-axis in contiguous slices from the mitral valve to the LV apex using a steady-state free precession (SSFP) imaging protocol (TR=30msec, TE=1.1msec, flip angle: 70°, slice thickness=6mm, spacing between slices=10mm, initial matrix size: 192x156pixel). Temporal resolution was 20 frames per cardiac cycle.

LGE-CMRI data was acquired after gadolinium injection (TR=700msec, TE=1.4msec, IT=220msec, flip angle: 10°, slice thickness=4mm, no gap, initial matrix size: 256x200pixel).

2.2. Image analysis

Custom software based on image noise distribution (for endocardial detection) and image gradient (for

Figure 1. Endocardial segmentation: a point is selected inside the LV cavity in the most apical slice of the ED frame (A); global segmentation is performed (B) then the final zero level set (C) is limited to the region of interest around the initial point (D) and used as initial condition for the endocardium detection achieved in two steps: local statistical level set (E, white contour) and the edge-based level set (E, green contour).

epicardial detection) was applied; the myocardium was automatically detected from SSFP images, and registered on LGE-CMRI data.

The first step of the analysis is the manual selection of one point inside the LV cavity followed by the application of a fast region-based global segmentation of the most apical slice of the end diastolic (ED) frame on the SSFP sequence (figure 1A). This global segmentation allows partitioning the acquired slice into maximally homogeneous regions taking into account the local noise patterns [5] (figure 1B). The final result (figure 1C) is limited to the region of interest around the initial point (figure 1D) and used as initial condition for a local segmentation obtained applying the same statistical model (figure 1E). Endocardial detection is refined by applying a boundary regularization achieved using curvature motion [6] that does not allow curvature above certain level and was designed to automatically include the papillary muscles in the LV cavity (figure 1E).

To identify the epicardial boundary we then used the classical edge-based level-set model [7] to search the image from the endocardium outwards. The equation that drives the evolution is the well-known Malladi-Sethian model for active contour evolution including a dependence of the speed on the curvature, a propagation expansion speed and an advection speed based on the image gradient. At the end of this step, the epicardium boundary is also regularized with a modified curvature motion (figure 2).

To obtain the segmentation of a frame, endo and epicardial segmentation was automatically repeated on each slice using as initial condition the centre of mass of the endocardial contour of the previous slice. For the segmentation of the next frames, the previously manually selected initial point was used and its position optimized considering the gray levels of the image.

The detected surface corresponding to the instant of time in which LGE CMRI data was acquired, is then registered on the LGE-CMRI data, considering the different acquisition parameters (figure 3).

The tissue inside myocardium was studied and scar tissue defined as myocardium with signal intensity≥80%

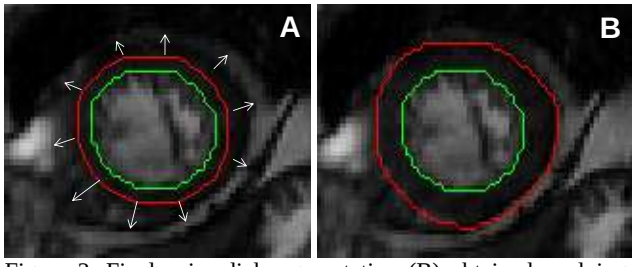

Figure 2. Final epicardial segmentation (B) obtained applying the classical edge-based level-set model to search the image from the endocardium outwards (A).

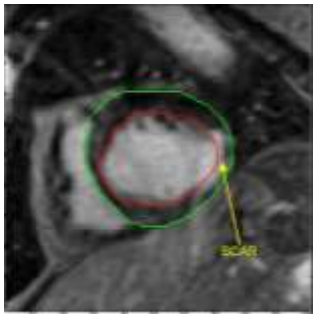
Figure 3. Example of scar detection in one slice of the LGE-CMRI data.

of its maximum and quantified on each slice.

An expert cardiologist provided the "gold standard" for scar location and extent on each acquired slice of the LGE-CMRI acquisition.

Scar location was assessed according to the standard segmentation model and compared with expert analysis; comparison of scar extent with "gold standard" was performed by linear regression and Bland-Altman analyses.

3. Results

Time required for automated analysis in one slice was only few seconds, for a total of 5-6 minutes for scar localization and quantification on a standard pc.

An example of the detected contours in one frame is shown in figure 4, together with the corresponding 3D

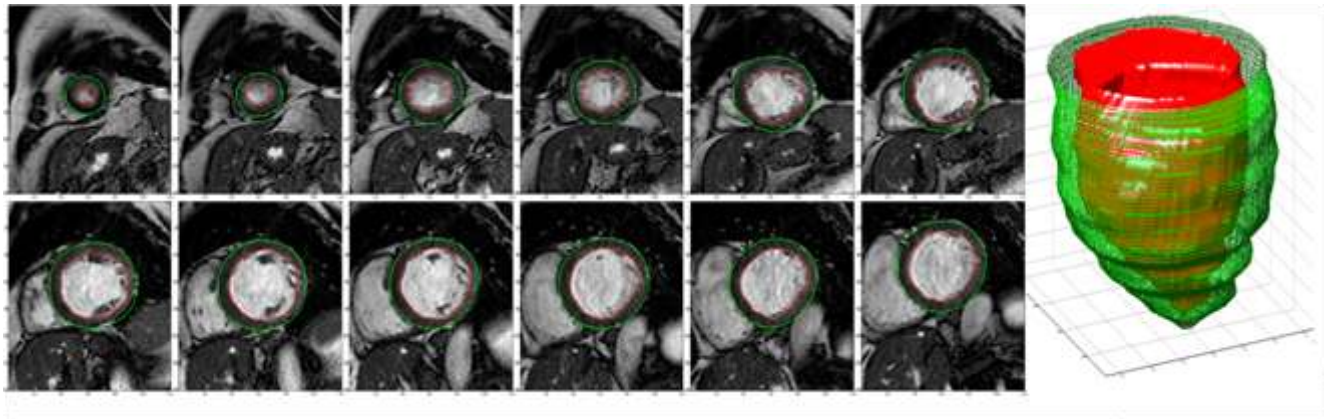

Figure 4. Endocardial and epicardial contours obtained in one frame from apex (top left) to base (bottom right) together with the corresponding 3D surface reconstruction.

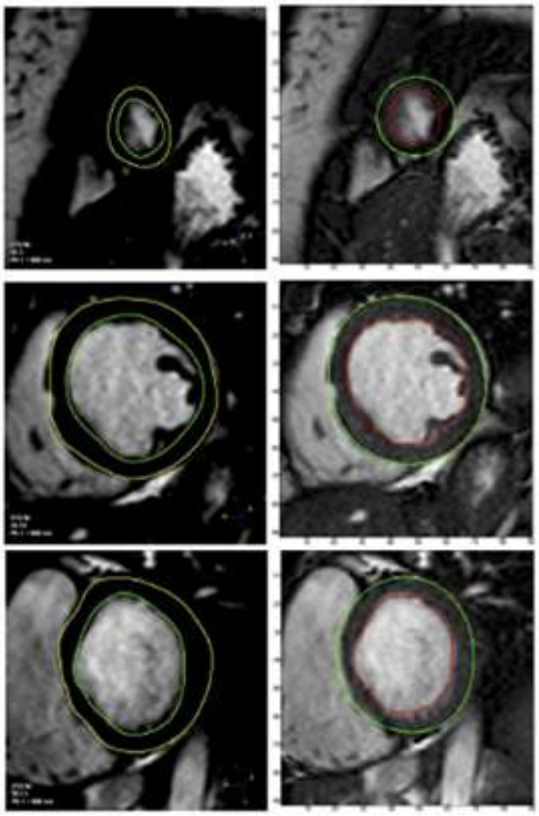

Figure 5. Examples of the automatically detected contours (right panels) and the corresponding manually traced ones (left panels).

reconstruction.

Endo- and epicardial boundaries were judged accurate in all image sequences. Examples of the automatically detected contours (right panels) and the corresponding manually traced ones (left panels) are shown in figure 5.

Cardiologist detected 7 scars (4 mid antero-septal; 2 mid and apical lateral, 1 apical posterior) for a total of 73 slices. Automated analysis evidenced 7 scars and located them in the correct position.

An example of a detected scar in one patient in the lateral segment is shown in figure 6.

A very good correlation (r=.96, y=x+0.06), non-significant bias (0.07cm^2, 2.5% of the mean reference value) and narrow limits of agreement (0.61cm^2) were found between scar area extent manually and automatically quantified. An example of the manually traced scar (left) and the automatically detected one (right) in one slice, in two patients, is reported in figure 7.

4. Discussion

In this study, we have presented a quantitative technique for segmenting myocardial scar in LGE-CMRI images, using myocardium information derived from SSFP data. We have applied this technique to images exhibiting visually distinct patterns of myocardial scar. A clear correspondence between the extent of myocardial hyper enhancement automatically quantified in LGE-CMRI images and the manually traced extent of myocardial scarring has been found.

Time required for the automated scar quantification could be further speeded up performing the analysis directly in the 3D space. Considering this improvement and following a comprehensive validation, this method could be suitable for clinical implementation. Importantly, the results of this analysis involve not only scar location and extent but also ventricular function being available dynamic endocardial and epicardial surfaces from which volumes, stroke volume, ejection fraction, mass, systolic and diastolic parameters could be easily derived and quantified.

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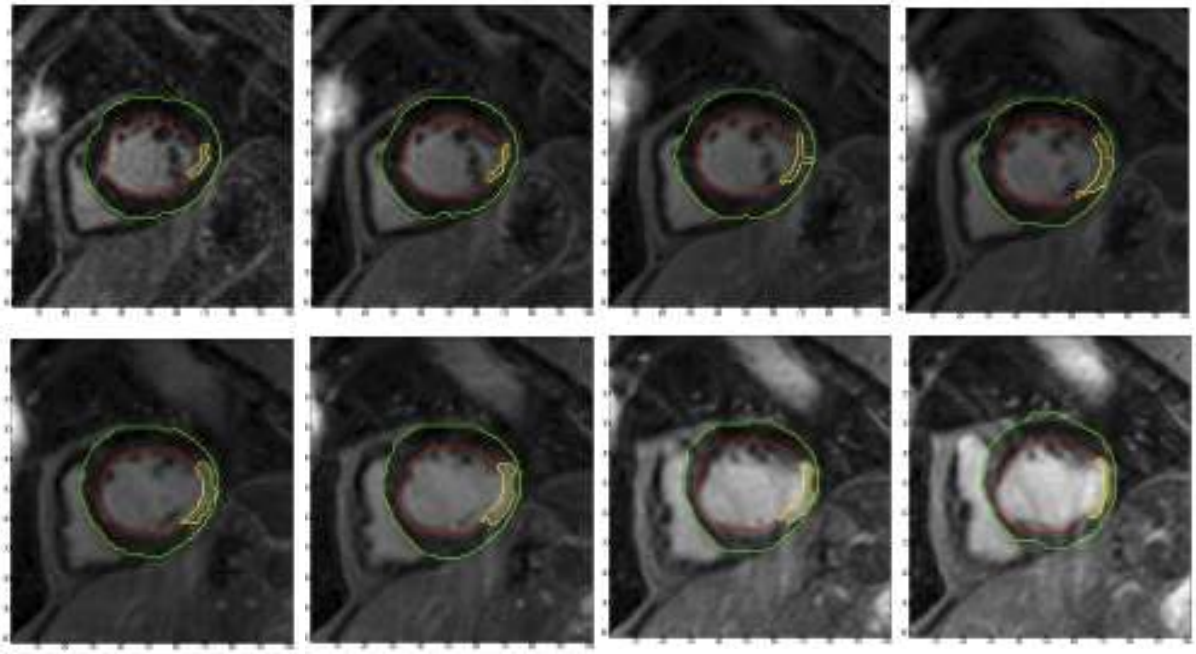

Figure 6. Example of scar detection from LGE-CMRI data in one patient: in red the endocardium, in green the epicardium and in yellow the detected scar.

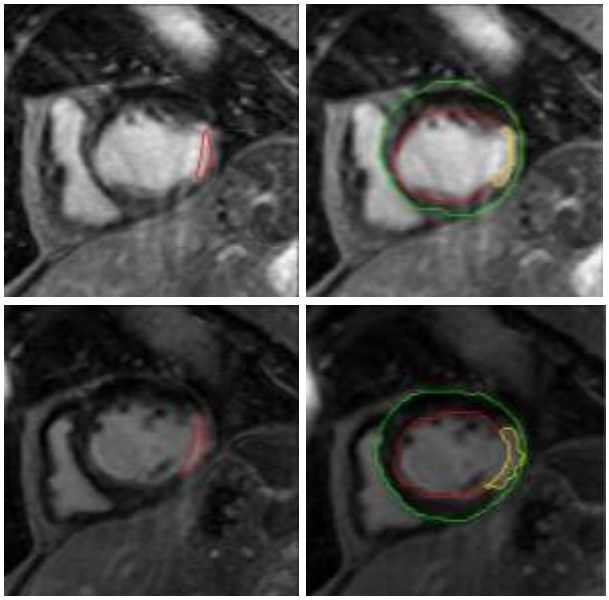

Figure 7. Comparison between scar contours manually traced (left) and automatically detected (right) in two slices belonging to two patients.

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