Quality control-driven artificial intelligence for reliable automatic segmentation of LGE images in clinical practice

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Background

Late gadolinium enhancement (LGE) cardiovascular magnetic resonance (CMR) imaging is well-validated for detecting focal myocardial lesions and fibrosis in a variety of cardiovascular diseases. Its analysis requires segmentation of the left ventricular (LV) myocardium, which involves manual contouring or usage of recent automated segmentation methods[1]. However, any unflagged segmentation deficiencies may result in inaccurate scar quantification or misdiagnoses. It is desirable to develop automated LGE segmentation that includes a quality control framework to ensure accuracy, in the absence of a ground truth reference, for reliable automation in clinical practice.

Methods

We implemented a quality control-driven (QCD) framework[2] to segment the LV myocardium on LGE images, which provides an inherent mechanism for predicting segmentation accuracy measured by Dice Similarity Coefficient (DSC). Imaging data of 326 hypertrophic cardiomyopathy patients from the multicentre Hypertrophic Cardiomyopathy Registry[3], with manual contours as the ground truth, were used for training with 15% of the data preserved for testing. LGE data was augmented three-fold by generating virtual native enhancement (VNE) images[4] for each subject using ShMOLLI T1-maps[5] and short-axis cines. In short, the deep neural network ensemble comprises of 12 candidate segmentation models including 6 different U-Nets[6] independently trained and 6 combinational models obtained via a label voting scheme. The quality control component involves a multiple linear regression model for each of the 12 candidate segmentation models. The segmentation with the highest predicted DSC is chosen on-the-fly for each LGE image. The accuracy of each selected segmentation was compared against the manual contours measured by DSC and the quality prediction accuracy by the mean absolute error (MAE).

Results

The QCD framework successfully and rapidly (<1 second per case) segmented the LV myocardium on LGE images with excellent contouring agreement with human analysts on both endocardium (DSC = 0.94, MAE = 0.04) and epicardium (DSC = 0.96, MAE = 0.03). The scatter plots (Figure 1) reflect the parity between the ground-truth DSC and the predicted DSC. With the resultant endocardial and epicardial contours, the LV myocardium masks can be derived by subtracting the endocardial masks from the epicardial masks (Figure 2).

Conclusion

The presented quality control-driven framework is an effective and robust deep neural network ensemble for LV myocardial segmentation on LGE images. It can improve the reliability of automated methods for immediate clinical interpretation.

References

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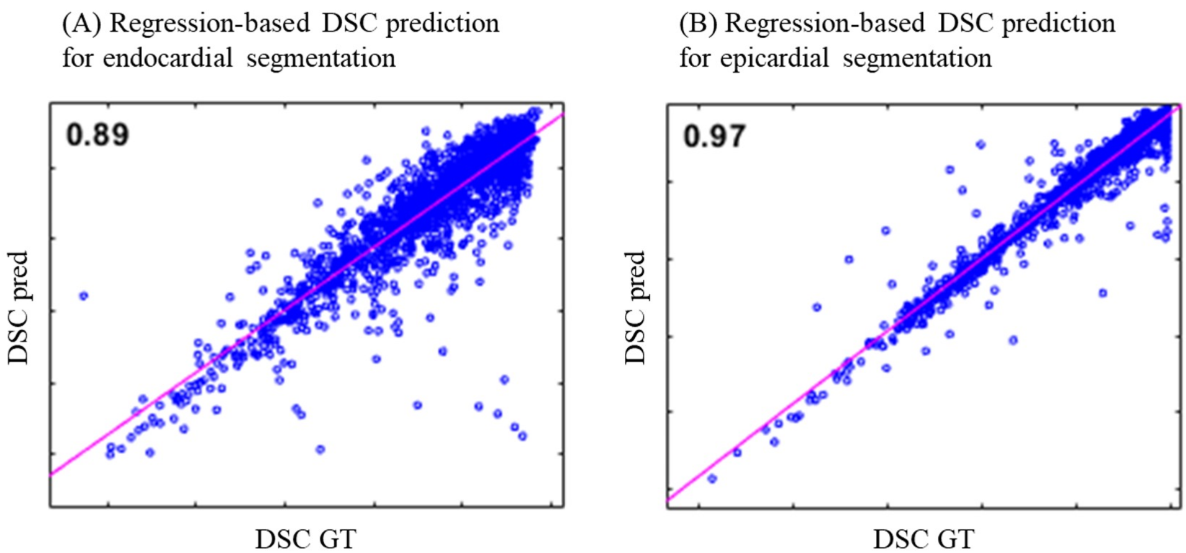

Figure 1. Scatter plots of the observed ground-truth (GT) Dice similarity coefficient (DSC) (x-axis) versus the regression-based predicted DSC (y-axis) for (A) the endocardium and (B) the epicardium on late gadolinium enhanced images, with shown correlation values.

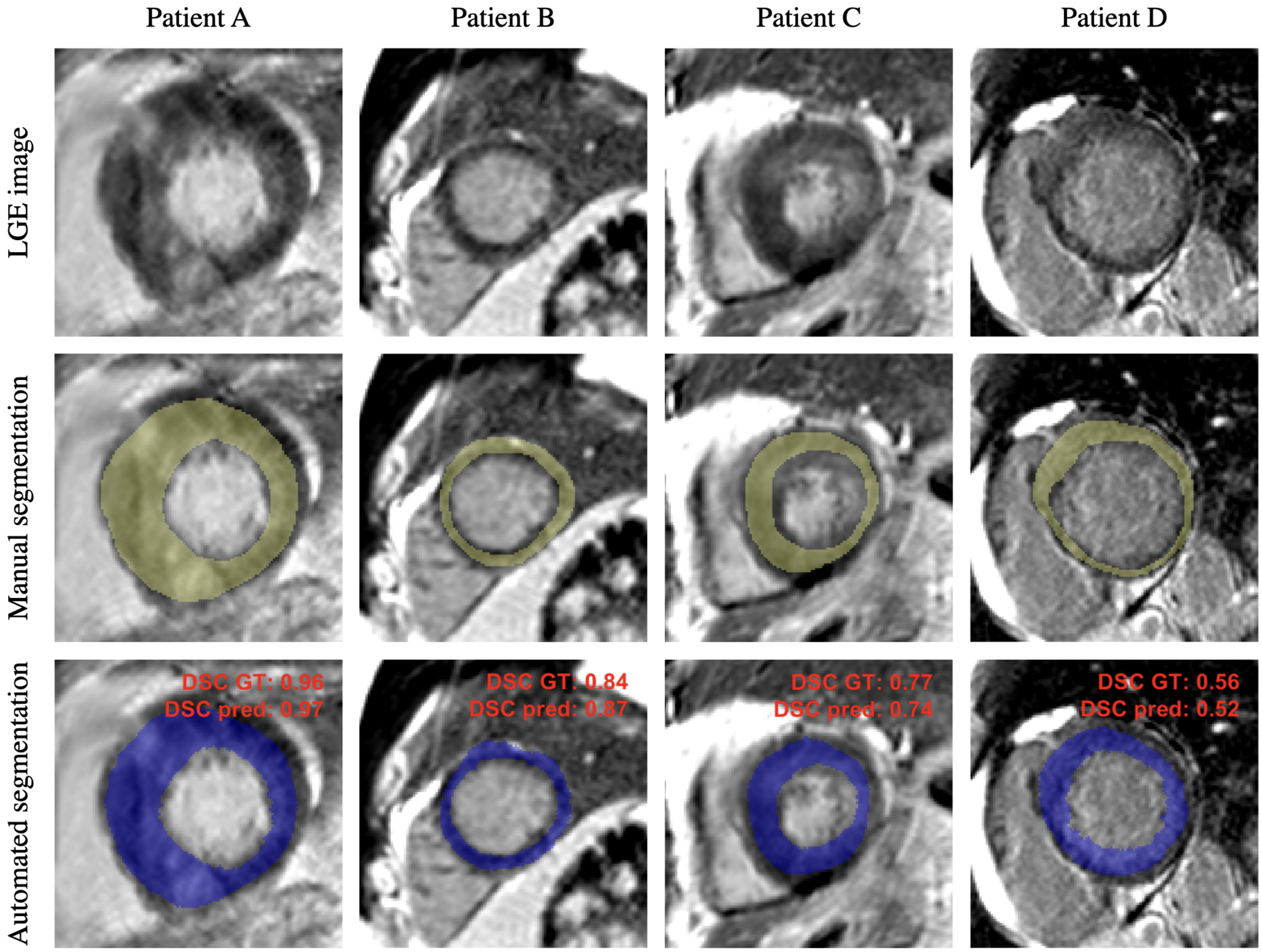

Figure 2. 4 examples of manual left ventricular myocardial segmentations (in yellow) and derived automated segmentations (in blue), with the corresponding observed ground-truth (GT) Dice similarity coefficient (DSC) and regression-based predicted DSC.