Comparison of Left Ventricular Curvedness Derived from CMR Imaging with the Wall Motion Score Index for Male Patients after First-Time Myocardial Infarction

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Abstract

The wall motion score index (WMSI) is an important clinical measure to assess the aggregate function of left ventricle (LV) wall segments after myocardial infarction (MI). Compared to global LV ejection fraction, WMSI provides additional information about regional functions that corresponds to myocardium contractility. Studies have shown that the WMSI yields powerful prognostic information after MI. However, one limitation of the WMSI is that manual assessment has to be performed by clinicians resulting in potential intra- and inter-observer variabilities.

In this study, we compared the geometry-derived curvedness at end-systole based on cardiac magnetic resonance (CMR) imaging with clinical WMSI in a group of 25 male patients presenting with first-time MI. Our computational method for calculating curvedness has the following advantages: it is automated and robust for a given set of inputs.

Comparing across basal, mid and distal segments, the mean values of curvedness at end-systole for segments with WMSI = 1 (normokinetic) were significantly different compared to segments with WMSI = 3 (akinetic) and above (p-value <0.05, 1-way ANOVA). We also observed significant difference in curvedness at end-systole for segments with WMSI = 1 compared to segments with WMSI = 2 (hypokinetic) at the mid segments (p-value <0.05, 1-way ANOVA). Our results suggest that automatically-generated curvedness may potentially be used for correlating to manually-assessed WMSI for patients after MI. Future work will include expanding the sample size of the patient group to validate our initial results.

1. Introduction

The wall motion score index (WMSI) is an important clinical measure to assess the aggregate function of left ventricle (LV) wall segments after myocardial infarction (MI). Such aggregate functional assessment is important for patient stratification and subsequent treatment strategy, follow-up and disease prognosis (such as the 1-year mortality risk) [1]. Compared to global LV ejection fraction (LVEF) which only provides a global assessment of LV function, WMSI provides additional insights into regional function corresponding to the active myocardium contractility.

Clinical assessment of the WMSI is routinely performed using 2D or 3D echocardiography and characterized using the standard 16-segment American Heart Association (AHA) nomenclature [2]. Each individual LV segment is assigned a semi-quantitative score to reflect its systolic function based on the visual inspection of the myocardium motion and its thickening (as a proxy for contractility) during systole. This score is defined on a 5-point scale based on the following criteria: score 1 = normokinesis or hyperkinesis; score 2 = hypokinesis; score 3 = akinesis; score 4 = dyskinesis and score 5 = aneurysm. The mean WMSI is then calculated by taking the average of the individual segment scores, thereby providing a proxy for the aggregate LV function. Previous studies have demonstrated that this mean WMSI have the potential to be used in a wide variety of clinical applications such as (i) independent predictor of death and hospitalization after acute MI [3], (ii) prediction of global LV ejection fraction [4] and (iii) predicting final infarct size in patients with non–ST-segment–elevation MI [5].

Despite the ease of WMSI computation using echocardiography and its potential applications, there are several inherent limitations to this approach of assessing LV function. The first limitation pertains to the use of echocardiography as an imaging modality for assessing myocardium motion and thickening. The American Society of Echocardiography and the European Association of Cardiovascular Imaging in their recommendation states that myocardium motion in

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individual segments can potentially be affected by tethering to adjacent segments and the overall motion of the LV. Hence the assessment of individual segment score should utilize multiple views and focus on the regional thickening to differentiate passive deformation from active deformation caused by the contractility of the myocardium [6]. The second limitation pertains to the reproducibility of results obtained using echocardiography, which is dependent on the skills of the operator and the quality of the acoustic window acquired during imaging [7]. As such, computation of WMSI using other imaging modality such as cardiac magnetic resonance (CMR) and multidetector CT imaging are gaining traction. However, regardless of the imaging modality used for acquiring cardiac motion, one outstanding limitation of the WMSI is that manual assessment performed by clinicians is still required. This method of assessment can still result in potential intra- and inter-observer variabilities especially among multi-center trials involving large number of patients and reporting clinicians.

In this study, we proposed the use of a 3D geometry-derived index for assessing the regional function of the LV that is the curvedness index at end-systole (C_{ES}). Our computational method for calculating curvedness has the following advantages: it is automated and robust for a given set of inputs. Our hypothesis is that C_{ES} can be used to assess the regional LV functions in a similar manner as the WMSI. To test this hypothesis, we compared C_{ES} computed based on CMR imaging with clinical WMSI in a group of 25 male patients presenting with first-time MI. The objective is to demonstrate that the values of C_{ES} is correlated to the WMSI score for the individual segments. In addition, we also compare the correlation of both the mean WMSI and mean C_{ES} across all 16 segments in the LV to the global LVEF to investigate if the aggregation of regional functions can indeed be used to predict global function.

2. Methods

The group of MI patient for this study belongs to a sub-group of MI patients recruited as part of their treatment protocol at the National Heart Centre Singapore. The population characteristics of the entire patient group and the imaging protocol has already been described in our previous work [8]. This sub-group of MI patients were selected for this study because of the availability of the WMSI.

In each subject, regional curvedness analysis was performed on reconstructed 3D geometry of the LV endocardial surface derived from contouring of CMR images for the entire cardiac cycle, and regional functions characterized using standard 16-segment AHA nomenclature. Further elaboration of the reconstruction methodology and the computational approach for calculating curvedness (based on an analytic approach using a local surface patch-fitting method) can be found in our previous works [9,10]. The robustness and reproducibility of our approach has also been demonstrated in our previous work [8]. All patients gave informed consent and were recruited without consideration of gender or ethnicity. The protocol used in this study was approved by the SingHealth Centralised Institutional Review Board.

3. Results and Discussions

The regional curvedness for all 16 LV segments were computed from the 3D reconstructed geometry. For analysis, we correlate the C_{ES} against the WMSI of the individual segments aggregated across the basal (segments 1 to 6), mid (segments 7 to 12) and distal (segments 13 to 16) regions. This stratification by segment position was required as the curvedness values at the distal segments are higher as compared to basal and mid segments; arising as a result of the tapered shape of the LV with the distal segments resulting in higher curvature at the distal region. The results are visualized using box-whisker plot in Figure 1. Comparing across basal, mid and distal segments, C_{ES} for segments with WMSI = 1 (normokinetic) were significantly different compared to segments with WMSI = 3 (akinetic) and above (p-value <0.05, 1-way ANOVA). We also observed significant difference in C_{ES} for segments with WMSI = 1 compared to segments with WMSI = 2 (hypokinetic) at the mid segments (p-value <0.05, 1-way ANOVA). Generally, the values of C_{ES} decreased with increasing WMSI as indicated by the decreasing median C_{ES} in Figure 1. This trend is observed across all regions (basal, mid and distal). Our results suggest that automatically-generated C_{ES} may potentially be used for assessing regional myocardium contractility and systole function for patients after MI, providing an alternative to the WMSI.

We also correlate the mean WMSI and mean C_{ES} across all 16 segments in the LV to the global LVEF for this group of patients. The results are shown in the scatter plots in Figure 2. From the figure, it can be seen that C_{ES} has a better correlation with the global LVEF. Using a linear regression fit, the R^2 for C_{ES} is 0.79 whereas the R^2 for mean WMSI is 0.65, suggesting that the mean C_{ES} has higher sensitivity to the global LV function. We hypothesize that this is a result of the WMSI being a semi-quantitative score (the scoring is discrete) as compared to C_{ES} being a continuous quantitative score.

4. Clinical Applicability

One possible clinical application for using the C_{ES} is for the assessment of myocardium contractility in all 16

segments during end-systole. This will allow the clinician to determine the location of the damage to the myocardium arising from the MI without usage of any contrast agent (e.g., late gadolinium-enhanced CMR for visualizing the degree and location of the infarction) or radionuclide tracer. Our approach has the potential to offer clinicians with new insights into the regional systole function and myocardium contractility after an infarction.

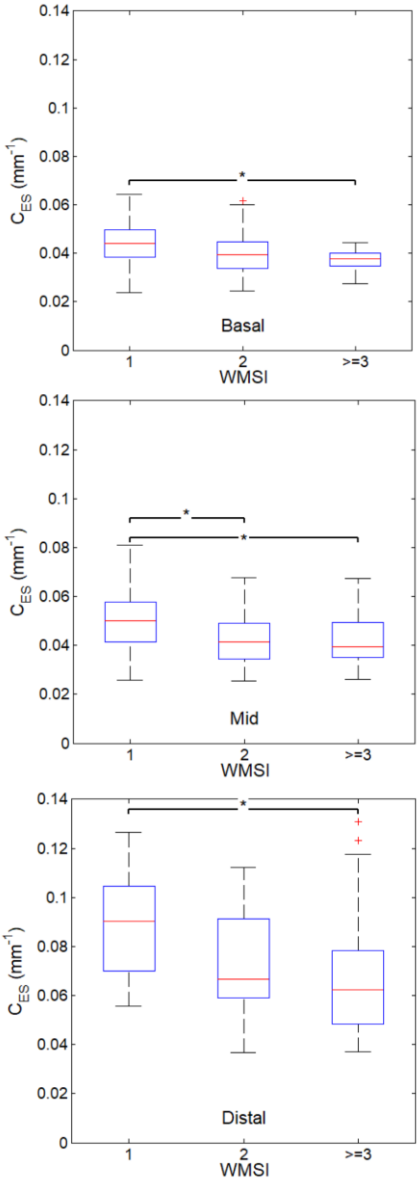

Figure 1. Box-whisker correlating the WMSI with C_{ES} for the basal region (top), mid-cavity region (middle) and distal region (bottom). In each box, the central mark (in red) is the median, the edges of the box are the 25th and 75th percentiles and the whiskers extend to approximately +2.7 standard deviation coverage if the data are normally distributed. Refer to main text for discussion of the results (* $p < 0.05$).

Such insights will be essential for both diagnosis (in terms of disease stratification) and patient management.

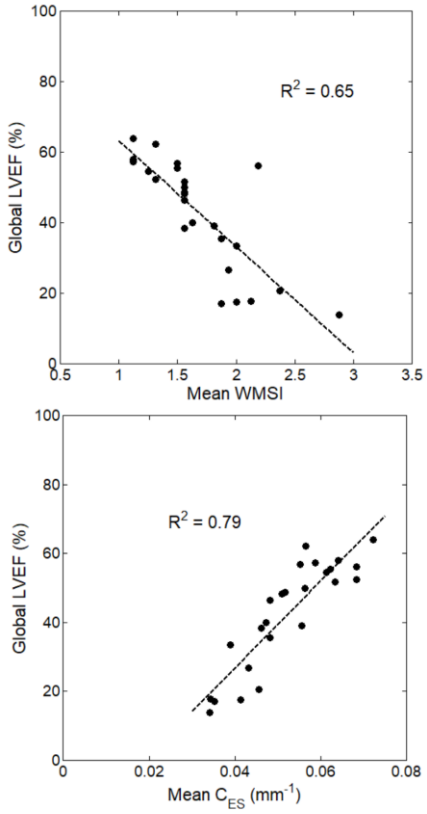

Figure 2. Correlation between the mean WMSI (top) and mean C_{ES} (bottom) to the global LVEF. The C_{ES} has a better correlation with the global LVEF. A linear functional is used to fit the data.

5. Limitations

Our approach for computing the regional curvedness is dependent on the segmentation of the endocardial surface from the CMR images. Currently, this segmentation is performed manually and can be potentially time-consuming. In addition, there is also a degree of variabilities in the contouring of the endocardial surface across observers though our previous work had demonstrated that our approach is robust to variation in the segmented input contours provided by the user [8]. The development of automated image segmentation techniques utilizing shape-based interpolation, super-resolution and deep-learning algorithms can potentially be used to automate the segmentation of the LV endocardial surface and to reduce the variability of the segmented contours (through reducing user inputs).

Also, we acknowledge that the statistical power of this study is limited due to the number of patients recruited (25 patients). Hence, the results reported will still need to be validated on a larger cohort of patients including

female patients to investigate if there is any gender differences in the C_{ES}. It will also be interesting to investigate if C_{ES} can be used to predict functional recovery in patients after the initial MI (such as correlating the final infarct size in patient after 1 year to the C_{ES} computed immediately post the initial MI). Such longitudinal studies can potentially impact the clinical management and treatment of patients with acute MI by stratifying patients based on the recovery prospect.

6. Conclusions

We have established a computational approach to compute the regional curvedness values at end-systole (C_{ES}) using the standard 16-segment AHA nomenclature by reconstructing the 3D geometries of the LV throughout the entire cardiac cycle. From this study, we observed the following results: (i) C_{ES} for segments with WMSI = 1 were significantly different compared to segments with WMSI = 3 (akinetic) and above and (ii) the values of C_{ES} decreased with increasing WMSI.

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