Normalized Wall Thickening Patterns for Detecting Cardiac Functional Abnormality from Cine MRI Images

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Introduction: Imaging the heart using cine MRI is a powerful tool for assessing the cardiac function. To assess global heart function, parameters such as left ventricular (LV) volume, mass, and ejection fraction are calculated from the cine images. However, in many cases, global functional parameters do not reflect subtle wall motion abnormalities. In such cases, assessment of regional cardiac wall motion is required. Methods for automatic quantification of the myocardial wall motion from standard cine images can be classified into intensity-based and contour-based methods [1-2]. The contour-based methods avoid the limitations of the intensity-based methods, as no assumptions are made about the myocardium/blood contrast or the LV shape and location [3-4]. In this study, we develop a technique that can detect regional wall motion abnormality based on capturing the variation in the myocardial thickness during the cardiac cycle. It is worth noting that although the normalized LV thickness is used as a clinical measure in echocardiography, it has not been used before for automatic assessment of cardiac MRI images.

Methods: An image dataset from 14 normal subjects and 13 patients (4 with myocardium infarction (MI), 5 with pulmonary hypertension (PH); and 4 with hypertrophic cardiomyopathy (HCM)) was used to train and test the proposed method. Three short-axis (SAX) slices (basal, mid-ventricular, and apical), each with 23-25 timeframes, were acquired for each subject using standard steady-state free precession (SSFP) cine pulse sequence, resulting in total of 1863 image. In addition to the cine images, Late Gadolinium Enhanced (LGE) images were acquired for the patients with MI. The endo- and epicardium were manually determined in each slice. Each contour was resampled at equi-angular spaces to a standard vector length of 60 points in the mid and basal slices and 40 points in the apical slices. At any given timeframe, the wall thickness was calculated at the k^{th} contour point as the radial distance connecting the k^{th} point on the endocardium to the corresponding one in the epicardium. The myocardial wall thickness was normalized by dividing the calculated distances by the mean radius of the epicardium (at the first timeframe). The normalized wall thickness values of all contour points within each segment were averaged to represent each segment by one normalized wall thickness (NWT) value (Figure 1). Principal component analysis (PCA) was applied to find the directions of data variations. The feature vector that represents the contraction pattern of each segment is created as the projection of its NWT through the cardiac cycle on the eigenvectors corresponding to the largest eigenvalues.

Feature classification was conducted using the maximum likelihood criterion with leave-one-out method over each segment (using 16-independent classifier) [5]. An experiment was designed to determine the minimum number of principal components (n) that achieves the best performance based on the F1-score, defined as F1 = 2TP/(2TP+FP+FN), where the true positive (TP), false positive (FP), true negative (TN), and false negative (FN) values are calculated using the leave-one-out method for each segment. A second experiment was conducted to evaluate the overall performance of the proposed method using the optimal number of principal components determined in the first experiment. Classification was applied to assign a label (normal or abnormal) to each segment, where equal prior probability was assumed for both classes. Slice abnormality was determined based on the number of abnormal segments, where a slice is considered abnormal if it contains one or more abnormal segments.

Results: The highest F1-score (highest accuracy) occurred when only one principal component was used. Consequently, the parameter n was set to 1 in Experiment 2. It is worth noting that in this experiment the largest component captured about 89% of all the data variations. Table I summarizes the results obtained from Experiment 2. The sensitivity and specificity for each slice level are also illustrated in the table. Higher specificity relative to sensitivity reflects the algorithm's tendency for true identification of normal cases over abnormal cases. For example, the hyper-enhanced segments in the LGE images (first row in Figure 2) correspond to the abnormal segments detected by the proposed method. However, it can be shown in the figure that some segments (e.g. segment 1 in Figure 2e) are classified as abnormal while they have normal intensity in LGE (Figure 2b). This may be explained by the fact that the LGE images show only the infarcted regions; not regions with abnormal wall motion (e.g. the peripheral zone). Among the different groups of patients, it was observed that the proposed method was able to detect abnormal cases with MI and HCM with better accuracy than the cases with the PH. This could be explained by the fact that PH is manifested mainly in RV, rather than LV, remolding.

Conclusions: In this work, we proposed a novel feature vector, namely the normalized wall thickness, which was used for detection of abnormal wall motion based on classification using the maximum likelihood criterion with leave-one-out method. The developed method considers the variations between normal and abnormal contraction by tracking the normalized thickness of all segments between the endocardium and epicardium during the whole cardiac cycle. The proposed method provides automatic assessment of the regional abnormality for each segment in each slice; therefore, it could be a valuable tool for automatic and fast determination of regional wall motion abnormality from conventional untagged cine images. Future work includes stratifying the results based on heart disease, which will require analyzing more patients.

References:[1]JCMR,8:427-33. [2]MICCAI,12:750-8. [3]IEEE-TBME,51:1923-31. [4]IEEE-TMI,28:595-607. [5]Elisseeff,"Leave-one-out error & stability",IOS Press

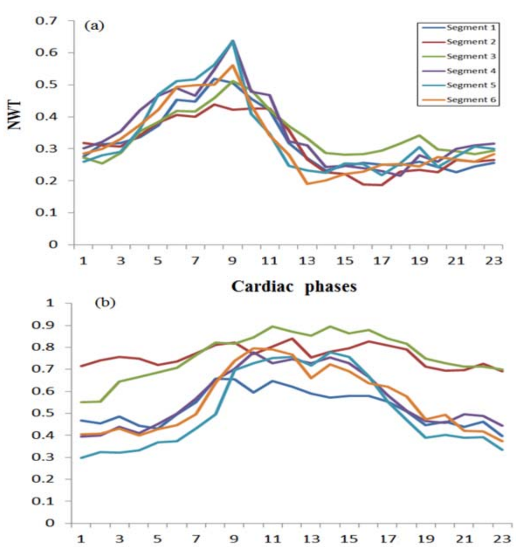

Fig.1. Normalized wall thickness throughout the cardiac cycle for all segments in a mid slice from (a) volunteer and (b) HCM patient.

Table I. Classification results according to one principal component (values represented as percentages).

Slice	TP	FP	TN	FN	Sensitivity	Specificity
Basal	92	8	79	23	92	77
Mid	77	23	86	14	77	86
Apical	77	23	100	0	77	100

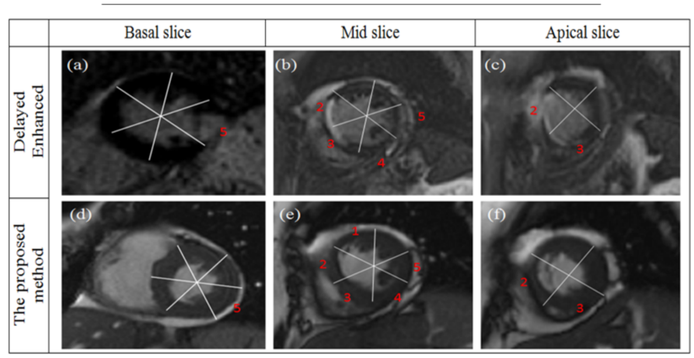

Fig.2. Comparison between infarcted regions using LGE MRI (a,b and c) and regions with motion abnormality detected using the proposed mehtod (d,e and f).