Short Communication

Quantification of Left Ventricle Function in Stress Echocardiography Using Endocardial Area Centroid Trajectory

Abstract

Coronary artery occlusion has a direct effect on cardiac activity and is a well-known reason for ventricular motion disorder, specifically left ventricle (LV) wall motion dysfunction. In stress echocardiography, wall motion abnormality is exaggerated when stress is applied to the heart, and therefore, it is easier to diagnose abnormality in ventricular motion. In this study, we have presented a new parameter that measures LV function. We have shown that LV function can be measured using a variation of endocard borders during a cardiac cycle in standard stress echocardiography frames. This parameter shows a meaningful difference between ischemic and normal hearts and is calculated at different heart rates (HRs). In conclusion, ischemic hearts cannot keep up with the required increase in activity when reaching peak levels of stress.

Keywords: *Coronary occlusion, coronary vessels, echocardiography, heart, heart rate, heart ventricles, ventricular function, stress*

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Introduction

Wall motion abnormalities are well-known symptoms of coronary artery disease (CAD), specifically myocardial ischemia (heart muscle disease due to coronary occlusion). The most simple and frequently used clinical test to demonstrate regional left ventricle (LV) function is stress echocardiography. The diagnostic and prognostic accuracy by stress echocardiography is similar to radionuclide stress perfusion imaging, but it is performed with substantially lower cost, without environmental impact, and with no bio-hazards for the patient and the physician. In this test, the ability of cardiac muscles in response to external stress is measured. There are three types of stress categories, namely exercise, pharmacologic stress, and pacing stress.[1] Patients who are capable of doing exercise use either a treadmill or a bicycle, and for those who cannot perform physical activities, dobutamine, and vasodilators are alternative pharmacological stresses. In patients with a permanent pacemaker, stress is induced by increasing the pacing rate. Each of these three stresses is used depending on the medical conditions.

Wall motion assessment is conventionally performed by visual interpretation of endocardial excursion and myocardial thickening. Consequently, it is subjective and strongly dependent on the specialist's experience. Picano *et al.*[2] evaluated diagnostic accuracy of visual interpretation in stress echocardiography. They showed that accuracy depended greatly on the experience of the physician interpreting the test. Therefore, the lack of a numerical quantity characterizing the quality of cardiac function is evident.

Until recent times, there have been efforts to quantify cardiac function. Derumeaux *et al.*[3] evaluated accuracy of tissue Doppler imaging (TDI) to quantify regional myocardial dysfunction induced by acute ischemia. On analyzing myocardium Doppler signals,[4] they showed that diagnostic ability of TDI could be improved for quantification of regional myocardial function. Arsenault *et al.*[5] used LV shape assessment to diagnose ischemia by extracting endocard border position in stress echocardiography images. Urheim *et al.*[6] suggested the usage of myocardial strain to quantify regional myocardial function, which could be measured by Doppler echocardiography as the time integral of regional velocity gradients.

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Until recently, only a few attempts were made to automatically classify heart motion based on combined information of rest and stress sequences. On the basis of stress echocardiography, Mansor *et al.*[7,8] employed a Hidden Markov Model (HMM) to classify local wall motion of the heart, and an improvement was achieved combining rest and stress information compared to separate individual sequences. Chykeyuk *et al.*[9] performed a local and global classification of wall motion by a new feature selection method to improve classification accuracy utilizing a relevance vector machine (RVM).

In this study, we have proposed a new approach to classify cardiac function based on combined information of rest and stress sequences by means of features extracted from endocardial area centroid trajectory. As it has been shown in Pearlman *et al.*,[10] we calculated centroids from LV cavity area to provide more reproducible data. By tracing the endocardial border and calculating centroid of area inside the border, for all the frames during a cardiac cycle, centroids trajectory was achieved, and features extracted from all trajectories during stress test showed different behaviors in ischemic and healthy individuals.

Subjects and Methods

In this study, we performed standard clinical dobutamine stress echocardiography (DSE) on five individuals, three men and two women, between the ages of 51 and 84 years, who were ischemia suspicious, two of whom had healthy LV wall motion and the other three suffered from ischemia, according to the medical reports. We utilized B-mode apical 4-chamber (A4C) ultrasound images with 256 gray levels, taken at peak stress, resting phase, and average heart rate (HR) between these two. At each HR, one cardiac cycle was extracted according to the included ECG signal between two consecutive R points [Figure 1].

For each case, the four-chamber view was segmented into seven parts[11] by a cardiologist, which were labeled as normal, hypokinesis, akinetic, and dyskinetic with numbers 1–4, respectively (the apical cap was normally ignored because of low resolution and difficulty in tracing).

As mentioned earlier, our proposed method extracted information from endocardial area centroid trajectory. The procedure is described as follows.

At first, a cardiology expert traced the endocardial border in each frame within a single cardiac cycle for all different HRs acquired in dobutamine stress test. Then, an area surrounded by this border was formed. This two-dimensional area, just like a thin layer of metal, had a unique mass center, in which the relative position of area mass summed to zero, meaning that if the region was cut out of a sheet of uniform density metal, it would be balanced on a pin placed at this center. This unique mass center for each traced region (R) was calculated as:

$$\bar{x} = \frac{1}{A}\iint_R x\,\mathrm{d}x\,\mathrm{d}y \tag{1}$$

$$\bar{y} = \frac{1}{A}\iint_R y\,\mathrm{d}x\,\mathrm{d}y \tag{2}$$

In this equation, $\bar{x}$ and $\bar{y}$ are horizontal and vertical positions of the mass center (i.e., centroid), x and y are horizontal and vertical coordinates, $\mathrm{d}x\mathrm{d}y$ is area elements of region R, and A is calculated as:

$$A = \iint_R \mathrm{d}x\,\mathrm{d}y \tag{3}$$

An important trait of this calculation was low sensitivity to isolated outliers because of low pass nature of integral operator. Therefore, the area specified by the boundary did not greatly change by malposition of a single boundary point.[10] Figure 2 demonstrates the procedure of centroid trajectory calculation.

When all points, one single point for each frame, were calculated during a cardiac cycle, we used k-means to cluster them into three groups, namely systolic, diastolic, and transient points [Figure 3]. Which name corresponded to which cluster was not important, but only that the transient

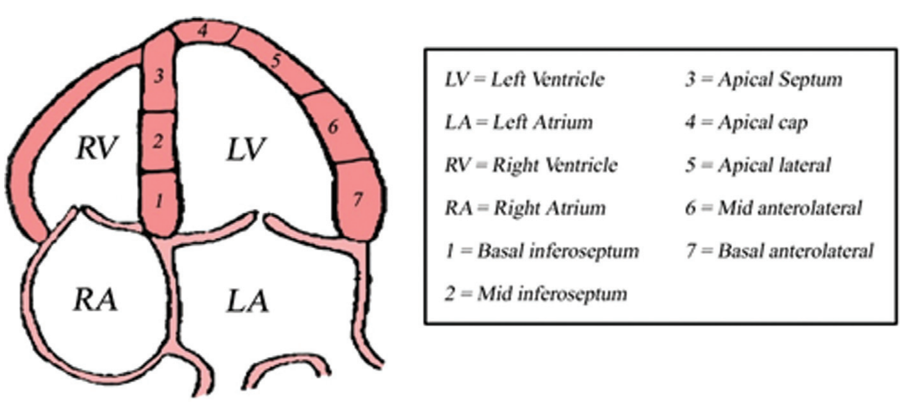

Figure 1: Standard segments of four-chamber view

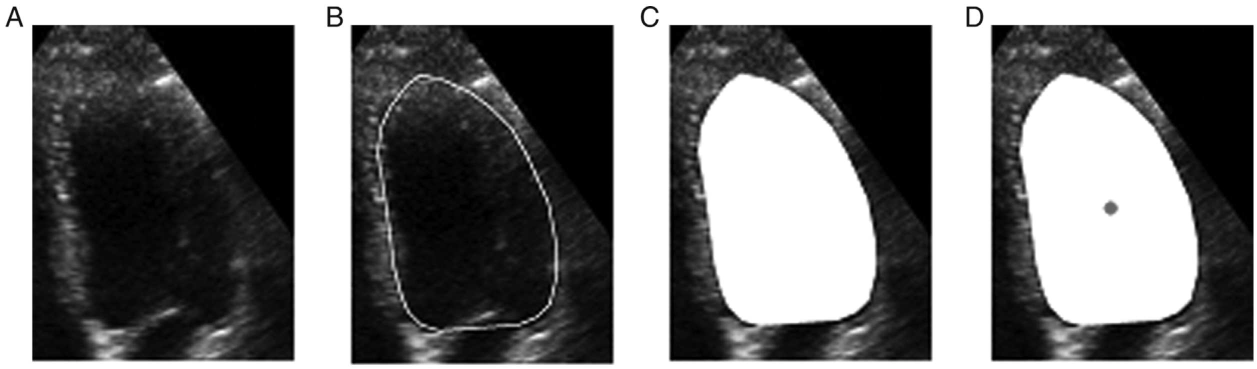

Figure 2: (a) Frame extracted from a single cardiac cycle. (b) Endocardial border traced by an expert. (c) Area surrounded by endocardial border. (d) Endocardial area centroid

cluster was always between the other two. The next step was to calculate the Euclidean distance between systolic and diastolic cluster centroids. The distance between these two clusters was a global measurement of cardiac wall motion during the cycle by which frames trajectory was obtained. Bigger distance between systolic and diastolic cluster centroids showed more contraction and relaxation during a cardiac cycle. This procedure was repeated for all HRs during stress test, which resulted in different activity values. The distance between cluster centroids increased in a normal case, as HR increased because of stress resulted by dobutamine injection. We expected more cardiac activity when stress was increased and, therefore, longer distance between systolic and diastolic cluster centroids.

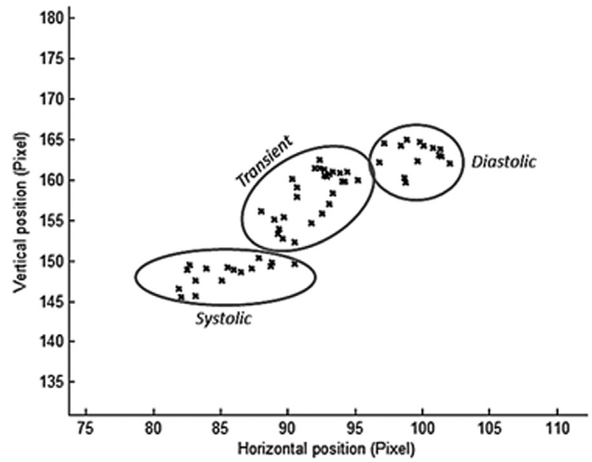

Figure 3: Clustering of cardiac wall motion trajectory points during a cycle into three groups in a normal case

Results

For a healthy individual, more stress was expected to result in more contraction and relaxation and consequently more distance between cluster centroids of systolic and diastolic points, though we expected an ascending diagram for cluster centroids distance against HR.

In the first column of Figure 4, centroids distance values of each individual was demonstrated for different HRs, from rest to peak stress. The second column showed how these values were changed by stress, that is, difference between consecutive points in corresponding first column figure.

As it can be seen, healthy individuals are capable of following stress increase while ischemia has caused a collapse in activity for the A, C and E diagrams in Figure 4. If all the cardiac activities were shown in the same plot, the difference could be seen better. Those who had collapsed peak stress activity were distinguished as ischemic, and is shown in Figure 5.

In some cases, for HR changes at rest or at the beginning of stress, there was a drop in HR even for healthy individuals. This is a natural behavior of the cardio vascular system on sudden HR change. It takes time for the blood vessels to dilate when HR increases at once, and as a cardiologist expert has proved, this can happen to everyone in a stress test.

Discussion

In this work, we have proposed a new parameter to discriminate between healthy and ischemic individuals using ordinary stress echocardiography frames. Variation of this parameter can show how cardiac function behaves during stress and brings us a simple description of stress echocardiography test from rest to peak stress. Finding borders of LV endocard, this parameter can help a cardiologist as an assistance tool for diagnosis.

Next, this method can be developed to find the location of LV dysfunction and lead to better diagnosis of the position of coronary artery occlusion by means of tracing trajectory of LV center of mass. By comparing healthy and unhealthy patients and tracing the geometrical center of mass in sufficient number of experiments, this measure can be a helpful measure of discrimination. Therefore, this quantity, easily calculated, can be considered to be a good measure for describing global functionality of the heart, which can be easily calculated with today's ultrasonic imaging systems.

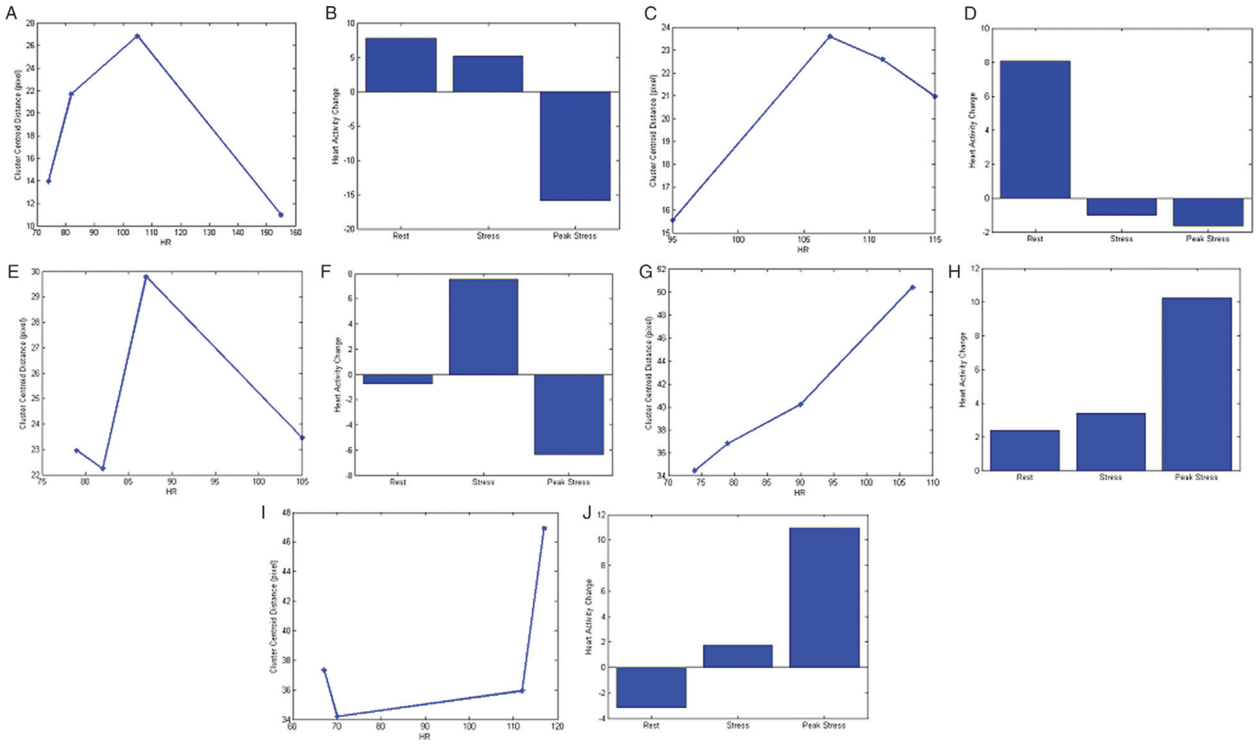

Figure 4: Distance of centroids (first column) and heart activity changes during stress (second column). The first three rows indicate ischemic individuals, and the last two rows indicate healthy individuals

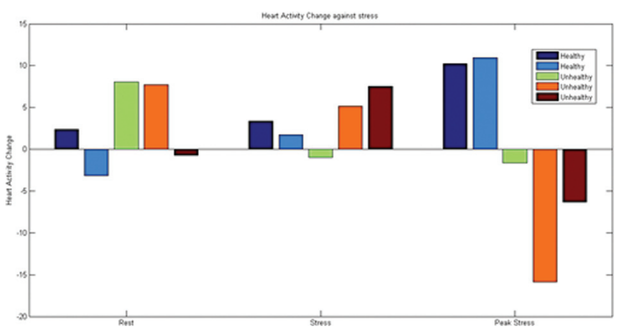

Figure 5: Heart activity changes in five individuals under various stress conditions

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Conflicts of interest

There are no conflicts of interest.

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