Computer-Assisted Detection of Ischemia Utilizing Echocardiograms Before and After Stress

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Abstract

Myocardial ischemia induced by stress may produce abnormalities of left ventricular (LV) wall motion. The location of wall motion abnormalities may be used to estimate the location and severity of coronary arterial obstructions. The American Society of Echocardiography has recommended the use of a 16-segment model of LV for assessment of wall motion abnormalities. Evaluation of motion of each segment of LV can be used to localize wall motion abnormalities (anterior, inferior, and lateral). Wall motion abnormalities can then be assigned to the distribution of each coronary artery. The normal response of the LV to stress is a uniform increase of regional wall motion, thickening and a reduction in end-systolic LV cavity volume, with minimal changes in diastolic cavity volume. Thus, echocardiographic comparison of LV performance before and after stress can be used to detect reversible myocardial ischemia.

Computer-assisted detection of ischemia is based on a quantitative analysis of LV wall thickness at end-diastole and end-systole. This paper presents an approach to computer-assisted detection of ischemia utilizing proper boundary identification, segmentation and comparative analysis of wall segments. The proper boundary identification includes an image pre-processing stage, contour detection and segmental analysis. The algorithm used in this study combines the detection of endocardial and epicardial boundaries, and the computation of the area of segments of LV wall. The technique is a modified form of two-phase relaxation active contour detection. The analysis of the LV wall segments before and after stress includes the computation of the area of a segment at end-diastole and end-systole. These areas provide the key values for monitoring LV wall motion.

1. Introduction

Myocardial ischemia induced by stress may produce abnormalities of left ventricular (LV) wall motion. The location of wall motion abnormalities may be used to estimate the location and severity of coronary arterial obstructions [1, 2].

The American Society of Echocardiography has recommended the use of a 16-segment model of LV for assessment of wall motion abnormalities. Evaluation of motion of each segment of LV can be used to localize wall motion abnormalities (anterior, inferior, and lateral). In this model, the LV is divided into three levels (as basal, mid and apical). The three levels are divided into three equal lengths using the papillary muscles as anatomical landmarks, as shown in Figure 1. The LV is further subdivided to produce a total of 16 segments [8]. The basal and mid levels are divided into six equal segments while the apical level is divided into four equal segments, as shown in Figure 2. Echocardiographic images of the three levels of LV can be captured using parasternal short axis views. Each segment of LV is assigned an anatomic location (anterior, inferior, and lateral). Ischemia due to obstruction of a single coronary artery usually produces a localized wall motion abnormality. Ischemia due to obstruction of more than one coronary artery usually produces multiple wall motion abnormalities. The distribution of wall motion abnormalities can be used to predict which arteries are likely causing ischemia.

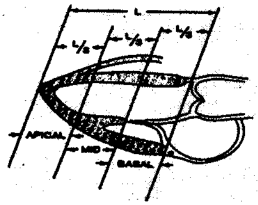

Figure 1. Division of left ventricle into basal, mid and apical levels

Figure 2. Parasternal short axis views at basal, mid and apical levels

The normal response of the LV to stress is a uniform increase of regional wall motion, thickening and a reduction in end-systolic LV cavity volume, with minimal changes in diastolic cavity volume [4]. The distinction between resting and stress induced regional wall motion abnormalities fundamentally differentiates prior myocardial infarction (MI) from reversible ischemia. Prior myocardial infarction is present when there is akinesia at rest, with dyskinesia or persistent akinesia after stress. Reversible ischemia is present when normal contraction or hypokinesia is present at rest, with new hypokinesia after stress Thus, echocardiographic comparison of LV performance before and after stress can be used to detect reversible myocardial ischemia.

Computer-assisted detection of ischaemia is based on a quantitative analysis of LV wall thickness at end-diastole and end-systole. The process can be split into three parts. First, the LV wall boundaries are identified. Next, theLV is separated into segments. Finally, segmental wall motion is assessed from echocardiographic images at end-diastole and at end-systole.

The basic requirement of quantitative analysis echocardiographic images before and after stress is the identification of the complete inner (endocardial) and outer (epicardial) boundaries of the LV wall. Computer-based identification of these boundaries in echocardiograms by using image processing and computer vision methodologies is a difficult task due to the intrinsic limitations of echo imaging such as speckle noise, image drop outs, boundary discontinuity, and disturbances in the images by valves, papillary muscles, et cetera [6]. Some of the major problems associated with endge detection are illustrated in Figure 3. As a result of the clustering threshold, a typical boundary detection algorithm will produce a number of regions for which enhanced edge detection methods are required.:

- Closed contours on the ventricle wall require aggregation into a larger cluster.
- Closed contours inside the ventricle do not belong to the wall in consideration and should be filtered.
- Parts of the wall that are not detected, (contours that include part of the wall as an internal part of the cluster) should be identified.
- Parts of the wall that are identified as boundaries of the ventricle, should be separated from the rest of the heart.

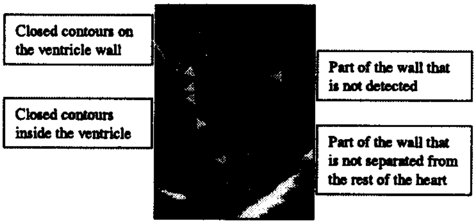

Figure 3. Issues in the identification of ventricle boundaries in echocardiographic images

This paper presents an approach, to computer-assisted detection of ischemia, which includes proper boundary identification, segmentation and further comparative analysis of wall segments.

2. Proper boundary identification

Straightforward application of bitmap clustering, and contour detection algorithms, may identify only parts of the ventricle wall (Figure 3). Our proposed computer-assisted detection of ischaemia, which is based on echocardiographic image sequences, includes the following stages:

- Image pre-processing and cleaning
- Contour detection and segment computation

Each stage is presented in detail, below.

2.1. Image pre-processing

Some of the factors mentioned above, and others, may limit the signal-to-noise ratios of raw echocardiographic images. Pre-processing may reduce the noise level and make homogeneous regions more uniform. Image pre-processing includes adjustment of grey-scale, tonal corrections by adjusting the values of the highlight and shadow pixels in the image, and setting an overall tonal range that allows for the sharpest detail possible throughout the image. In an extreme case this can be a black/white separation with respect to a particular threshold, as illustrated in Figure 4, where the threshold for the clusters is computed on the basis of the grey values of the pixels in the corresponding cluster.

Of the several filters available, mathematical morphology [7], using opening and closing concepts, proved to be most effective technique for emphasizing the epicardial and endocardial boundaries of LV walls.

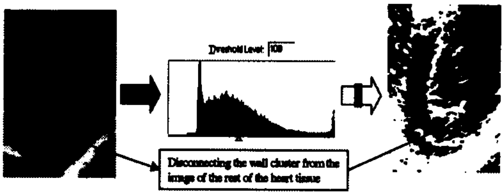

Figure 4. Example of simple image pre-processing step that facilitates contour detection.

2.2. Contour detection and segment computation

Several approaches of contour detection have been proposed in literature[4]. The algorithm proposed in this paper combines the detection of endocardial and epicardial boundaries, and the computation of the area of a segment of LV wall. It is based on a modified form of two-phase relaxation active contour detection technique [3]. The algorithm for detection of contours and computation of area of LV wall segments has the following steps:

1. Detect initial points on epicardial and endocardial boundaries in the image using two different threshold values.
2. Close the contour using active contours.
3. Divide the area covered under epicardial and endocardial boundaries into equal six or four segments depending on the level of image (six segments at basal and mid levels, four segments at apical level).
4. Count pixels in each segment.

Using this algorithm, we can approximate the area of each segment of LV wall. The data may then be used for further 2D or 3D modelling of the LV.

3. Analysis of segments of LV wall

The area values of each segment at end-diastole and end-systole before and after stress are essential for evaluation of LV wall motion. Normally, the change of LV wall dimensions from rest to stress is uniform in all segments. Variations from normal may be used to detect reversible ischemia as follows:

Let C be contractility of a segment of LV wall.

C ={ES, ED, Sn, Aesn, Aedn}

ES is an end-systolic image.
ED is an end-diastolic image.
S_n is number of segments of epicardial boundary (either 4 or 6).
A_{esn} is area covered between epicardial boundary and endocardial boundary in n^{th} segment in end-systolic image.
A_{edn} is area covered between epicardial boundary and endocardial boundary in n^{th} segment in end-diastolic image.

C can be expressed:

$$C = | A_{esn} - A_{edn}| \quad \text{-------} \; 1$$

Let C_{bn} and C_{an} represent contractility of segment n before and after stress, respectively.

Variance in contractility VC of segment n is expressed as follows:

$$VC_n = |C_{bn} - C_{an}| \quad \text{--------} \; 2$$

Average variance AV is computed using the variance in all segments.

$$AV = \frac{\sum_n VC_n}{n} \quad \text{-------} \; 3$$

Abnormality of Motion (AoM) of segment n can be expressed as follows:

$$AoM_n = \frac{VC_n - AV}{AV} \quad \text{-------} \; 4$$

The descriptor AoM is helpful in detection of the pathological condition of individual segment of LV wall if the myocardial ischemia has minor affect. In case of abnormal motion of all segments of LV wall, above equation (1) can be used as an indicator.

4. Results

Our algorithm should provide an automatic method of to quantify contractility of each segment of LV wall. This may be used to detect myocardial ischemia .

5. Discussion and conclusion

In the normal heart, there should be uniform echocardiographic augmentation of contraction with stress. Variations from normal may be used to detect reversible ischemia [8]. Abnormal contraction after stress may include:

1. Akinesia
2. Dyskinesia (aneurysmal dilatation)
3. Hypokinesis

We hope that quantitation of abnormalities of regional wall motion may be used to assess the location and severity of coronary artery disease. Effective and appropriate management of echocardiographic noise is essential to this method. Ultimately, findings from this analysis should be compared with angiographic and other functional assessments of myocardial ischemia, to establish the relative value of our methods.

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