Segmental Quantitative Analysis of Myocardial Contrast Echocardiography Images Using a Bullseye Representation

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Abstract

In this study, we describe a new method for representing myocardial contrast echocardiography (MCE) images, which provides an integrated and objective evaluation of left ventricular (LV) myocardial perfusion. MCE images were obtained in parasternal short axis views at mitral valve, papillary muscles and apical levels in an animal model of acute myocardial infarction. A software was developed to analyse MCE images, providing: 1) manual definition of myocardial borders; 2) automated division of LV in 16 segments; 2) quantitation of blood flow and texture analysis in each LV segment; 3) Color and numerical quantitation of blood flow distribution and texture entropy for each segment displayed as a bulls-eye representation of the 16 LV segments. This bull-eye representation provides additional quantitative information regarding global distribution of perfusion.

1. Introduction

Myocardial contrast echocardiography (MCE) has emerged as a promising technique for quantitative evaluation of myocardial perfusion. Considering the ability of MCE for assessing microvascular integrity, this technique may be useful for quantifying myocardial viability after sucessful reperfusion in acute myocardial infarction [1] and to estimate infarct size [2]. To quantitatively analyse the different patterns of myocardial opacification following coronary occlusion and reperfusion, in this study, we propose a method that is able to aggregate information from myocardial contrast images and tissue characterization analyzes to compose a myocardial perfusion and texture polar map of the left ventricle in an animal model of myocardial infarction. To fulfill this task we used computational algorithm tools for image processing, especially those for registering and segmentation.

2. Experimental preparation and protocol

The study protocol was conformed to the American Heart Association "Guidelines for Use of Animals in Research.". The proximal portions of the left anterior descending and left circumflex coronary arteries were dissected free from surrounding tissues in six open-chest anesthetized dogs. Catheters in both femoral veins were used for administration of fluids and infusion of microbubbles. Myocardial perfusion images were obtained in real time during continuous intravenous infusion of a perfluorocarbon containing albumin microbubbles (PESDA). MCE images were obtained with a Sonos-5500 system (Agilent-Phillips). The transducer was positioned and fixed distal to the occlusion. A dynamic range of 60 dB was used. At the beginning of each experiment, we adjusted and kept constant: depth, focal point, and gain. To obtain optimal myocardial opacification and minimal posterior wall shadowing, the infusion rate was adjusted for each animal between 1 and 3 ml/min. Left anterior descending or left circumflex coronary arteries were occluded for 1 to 3 hours.

3. Image treatment

MCE images were obtained in paraesternal short axis views at mitral valve, papillary muscles and apical levels. Images were digitized and analyzed off line. Using these images, we consider left ventricular segmentation as previously [3] standardized by the American Society of Echocardiography - ASE (Figure 1) in sixteen segments.

This segmentation can be performed taking as the starting point the atrium-ventricle junction. Then the myocardium was manually divided in four angular segments at the apical level, or six angular segments at the papillary and basal levels. For adequate left ventricular segmentation it is important an exact delimitation of myocardial borders. For this task some semi-automatic methods exist, including techniques that manually select a point in the ventricular cavity or define the central point of the ventricle [4,5], a region of interest in the image [6], or even, manually defined edges at one or more frames in the cardiac cycle [7]. Images were aligned by use of computer cross-correlation.

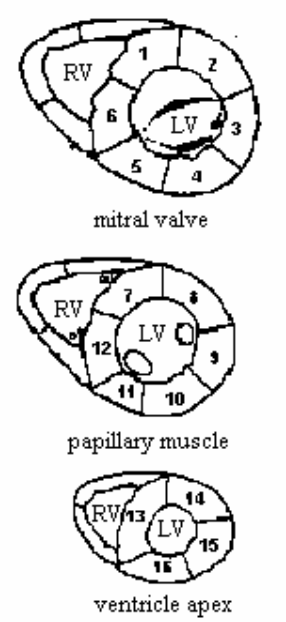

Figure 1: ASE segmentation for left ventricle.

After segmented, the image sequences need to be registered. The loop sequence was submitted to a non-rigid registration model [8], and then, estimated the blood flow for each segment. The cross correlation measures were used for similarity estimate in registration algorithm. Furthermore, the average entropy of texture co-occurrence matrices was also calculated for each segment.

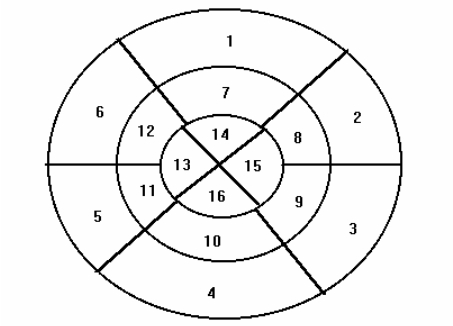

Figure 2: Bull's Eye schema for left ventricle.

Myocardial contrast video-intensity was quantifyied for each of the sixteen segments, and then transferred to the bull's eye map at its corresponding localization. Therefore, two bulls-eye maps were created representing perfusion and texture quantities.

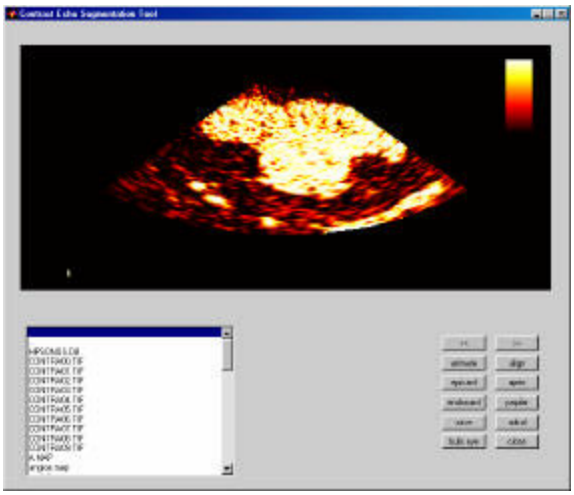

Figure 3: software tool showing a contrast image

4. Quantification of the blood flow

Through the continuous infusion of contrast, the microbubbles tend to assume the same hemodynamic behavior of the blood cells. With this we can assume that the microbubbles are tracer for the blood flow, or either, when measuring the flow of bubbles we are measuring, indirectly the blood flow [9].

Assuming that microbubbles are managed in intravenous continue infusion at a given contrast infusion rate and bubble concentration. After the stationary state is reached, considering that all the microbubbles are destroyed with an only pulse of ultrasound in the range of the beam, the process of refill of the region is initiated. Therefore, changing of videointensity in time follows the model proposed for Wei and col. [10]:

$$y = A(1-e^{-bt});$$

where y is the videointensity, A is the plateau or the saturation level of the videointensity representing the myocardium blood volume, and b represents the average speed of the microbubbles.

Since microbubbles were administered as a continuous infusion, after their destruction within the myocardium and measurement of their myocardial reappearance rate at steady state we can measure mean myocardial microbubble velocity and their myocardial concentration at steady state which provides assessment of microvascular cross-sectional area. As blood flow is the product of the average speed for the area of the transversal section, the myocardium blood flow will be proportional to the product of the plateau of video-intensity for the average speed of the microbubbles (A x b). Quantifying flow of microbubbles for each one of segments ASE (Figure 1), we were able to represent flow distribution through a polar map of the left ventricle. (Figure 4)

5. Texture analysis

Myocardial contrast opacification heterogeneity based on gray level differences in each ventricular segment was quantifyied. Echo textures was analyzed by using co-occurrence matrices, which were constructed for each pixel in the area of interest comparing pairs of gray levels in surrounding pixels and evaluating related properties using second order statistics [1]. For each neighborhood the co-occurrence matrix is calculated and then the entropy of this matrix. Later, the average entropy and maximum entropy for each angular segment inside of the myocardium are taken.

The texture analysis was performed defining a neighborhood of twenty points in which was calculated the co-occurrence matrix and its respective entropy; this neighborhood is dislocated on the interest region (myocardium segment). Then, for each segment was calculated the average entropy, and this is shown in the polar map. A polar map for one case is shown in the figure 4 (bottom).

6. Segmentation tool

To facilitate the task with the images, it was constructed a software integrated with graphical interface destined to the segmentation and quantification of the parameters in the images (Figure 3). This graphical interface integrates the algorithms of semi-automatic segmentation, alignment of the frames, perfusion quantification, analyzes of texture, and construction of the polar maps.

Software is capable to read the recorded images from magneto-optic disk in a private format derived from standard TIF, which are added tags with some additional information about the exam, patient, equipment, conditions of acquisition and storage of the images. In an extended TIF file can be found, for example, the ECG signal captured during the examination, and the values of lateral and tim gains adjusted by the ultrasound operator during the examination. These files are capable to store some frames in a Loop, and additional information in color frames, concentration of contrast bubbles or Doppler speed for instance. The development of this reader was possible thanks to the specifications of the format yielded by the manufacturer through its representative.

The development of a friendly interface for processing of the images is imperative, on the other hand, because an agile processing was necessary, and, for another one, so that the user could execute these procedures without the presence of the programmer. It is essential that an amount of images can be processed with easiness, precision and agility. Considering that they are acquired, in average 60 frames for each plan, and that are necessary three plans to form the polar map (bull's eye), 180 echocardiographic image files are necessary to compose one bull's eye. On the other hand, these images can be stored for revision or future processing. The graphical interface, called segmentation tool was developed within the *Matlab*[R] environment, which involves objects and functions for graphical interface creation.

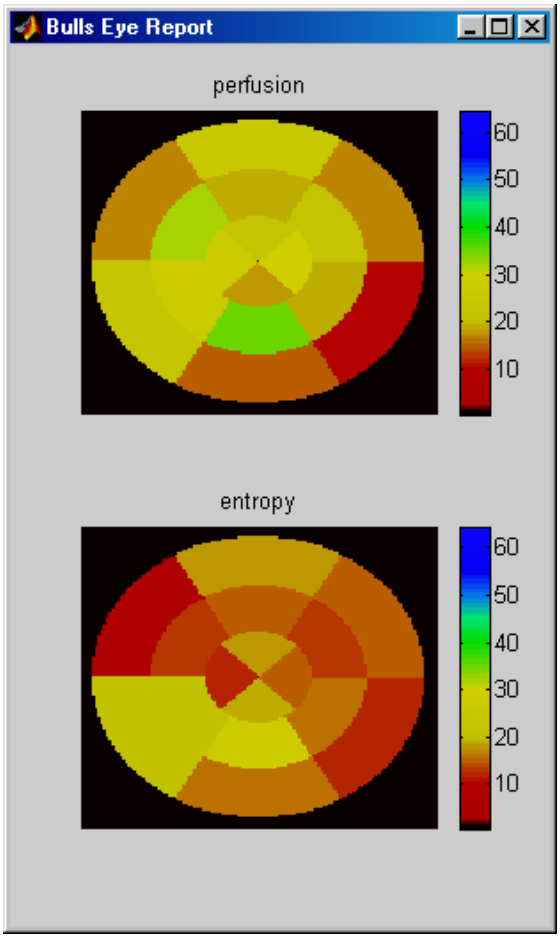

Figure 4: Bull's Eye display for perfusion quantification (top), and entropy estimation (bottom).

The left inferior field of the main window is used by the user to browse through the directories tree of the disk where the exam files are stored. By doing this the user has opportunity to select the desired image file, since the files containing the images of each individual are stored in different directories. The buttons < < and > > move the frames forward and backward within the time sequence of the loop. The button animate creates an animation with the available frames sequence so that the Loop can be visualized. The function aligns lines up the frames, correcting motion artifacts through the registered algorithm. With the functions endocard and epicard the user manually traces the limits of the endocardium and epicardium respectively defining the region where the quantifications will be performed. The mitral, papillary, and apex function initiate the angular segmentation in the aligned starting from a manually entered point and process the quantifications for each segment. The function save stores, at any instant, the calculated segmental quantifications. The function Bull's Eye constructs the polar maps

7. Conclusions

This software tool shows to be promising in contribute toward a better using and understanding of contrast echocardiography. The algorithm used for image registering showed to be reliable for the images used, but need to be tested for a greater number of cases and physiological conditions. This bulls-eye representation of myocardial perfusion and texture entropy provides additional quantitative information regarding global distribution of perfusion.

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