Methodology of Locating Myocardial Dysfunction by Strain and Strain Rate Using 4D Discretely Acquired Trans-Esophageal Echocardiogram

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Abstract

The article reported a methodology and a system development to locate the area of myocardial dysfunction using Trans-esophageal Echocardiogram (TEE). The gated and discretely acquired left ventricular TEE images were first delineated and were reconstructed into 3D wire mesh. In tracing the normal vector of contour and centroid of LV chamber, the distribution of centroid appeared in a function of natural logarithm decay which was significantly distributed within 1 mm radius. The minimum size for evaluation myocardial dysfunction was calculated and reported. The distribution of angle for normal vectors was tallied. The distribution was peaked at ±6 °in range. The effected size of dysfunction area can be carefully observed is 0.25 cm^2 for 5 cm diameter size of heart. This means that the dysfunction of local area, such as LAD area of myocardial can be examined using reconstructed 4D LV model using TEE images.

1. Introduction

Recently, the resolution, the accuracy and the acquisition time of 4D echocardiogram imaging system are significantly improved. The excellent temporal and spatial resolution made the study of the regional and the global cardiac strain during contraction and relaxation period possible. Many researchers have reported using 3D and 4D cardiac imaging dataset in studying the ventricular functions [1.2]. However, in evaluation of ventricular performance using such imaging techniques, many cardiologists and researchers have being segmenting 3D left ventricular (LV) surface into 16 segmental ventricular mapping, for example, in 2D echo assessment [3,4]. The ventricle was divided into three levels for further segmentation, namely, the basal, the mid and the apical areas along long axis of ventricle. The basal and the mid levels were segmented into six sections. The orientation of segmentation was counter-clockwise direction with aortic valve at 90°and viewing LV from the apex. The apical level was segmented into four sections for its size. The nominated segmental mapping was not able to pronounce the resolution of modern technology.

In order to analyze the local dysfunction with imaging technique, 4D images of a completed cycle of heart beat were needed. The motion of endocardial strain and strain rate could be analogy to the cardiac functions in contraction and relaxation phase of heart beat [5, 6]. Therefore, the strain and strain rate during contraction and relaxation phase were needed to carefully study. To identify the area and the size of infarction, the dysfunction, one has to determine the effective spatial resolution from extracted data. Furthermore, these specifications of evaluation the ventricular performance will be enabling us to study ventricular hemodynamics non-invasively.

2. Methods

The images of echocardiogram for reconstructing the dynamic wire-frame models of LV was obtained from the digitized trans-esophageal echocardiograph (TEE) serial image by SONOS 2500™ made by Phillips medical Systems (formerly Hewlett-Packard and Agilent). The images were acquired with ECG gated using 90 angles (2º/view) and 33 frame/second to scan an entire heartbeat, mainly, at the interested area of ventricular view. The total number of images been analyzed and processed in this presentation was 1800 (90 angles by 20 frame/heartbeat) slice of images. The acquired spatial resolution TEE image was 108 by 216 pixels (image size). In this article, the motion vectors of strain and strain rate were reconstructed from the acquired TEE images. The reported self-developed program will extract data for study the temporal and spatial resolution required in the understanding the motion of the Left ventricle. The example used in this paper was from the patient with mitral valve regurgitation whom has poor LV function.

A self-developed software system written in Visual C 6.0 is designed to extract the interested parameters and to display the visualized data for 4D LV model. The software system is operated under Windows™ XP that installed in personal computer. The reported self-developed software system has been tested with more than 30 sets of TEE's image dataset from patients with various cardiac diseases.

The reported analysis system, first, delineated the contour of ventricular chamber by guided-automatic border delineation method with prior information. Then, 3D LV contours were reconstructed into dynamic model of ventricular shape in 5 minutes/heart beat. The contour delineation method utilizes less than 1% prior manual tracing contour as a guiding pattern to delineate the LV contour automatically. The active contour algorithm was used to extracted contour of LV chamber from initial images in Cylinder coordinates (Polarized Scan) [7]. The algorithm was insensitive to the choice of weights. However, the best parameters of weighting for reported snake algorithm were 0.3 and 0.3 for internal bending and external cost function respectively. Then, the LV chamber was delineated again in Cartesian coordinates (the process of resampling). Last, the 3D model of LV chamber was reconstructed for inspection. The 4D reconstruction of left ventricle with selected displaying angle using Z-buffer technique will be executed first to view the reliability of acquired dataset. The 4D wire frame reconstruction of LV with previously delineated contour was executed next to further verify the acquired dataset. The LV volume was calculated and calibrated with known volume of water balloons.

Then, the calculation of physiological parameters and the extraction of shape information would be carried out and displayed visually. Some parameters that related LV volume, such as Ejection Fraction (EF), were also calculated. The bull-eyed display was used to describe the shape information, such as left ventricular chamber radius at various contraction phases [1]. To determine the radius at each slice of LV image, one needs to determine the center point of the LV chamber at the given slice of LV image. For this system, the center point was determined by contour centroid method [4]. The collections of the centroid point of each reconstructed imaging slice in Z-direction were formed that was representing the reference long axis of LV chamber. The floating long axis was used as the reference to the extraction of shape information for further shape, strain and strain rate analysis. The regional and the global shape description, the segmental curvature of LV, were calculated from the reciprocal of radius of each reconstructed imaging segment. The strain and the strain rate were calculated from the difference of length at segmental contour of LV between two time frames. The strain and the strain rate were studied. The range of distribution for the strain and the strain rate in systolic as well as diastolic phases was tallied separately. In this article, the LV was segmented into 900 blocks for analysis of the regional shape, the strain and the strain rate. The method of determining the number of blocks and block size was based on the traceable point on the contour using the method of optical flow [8].

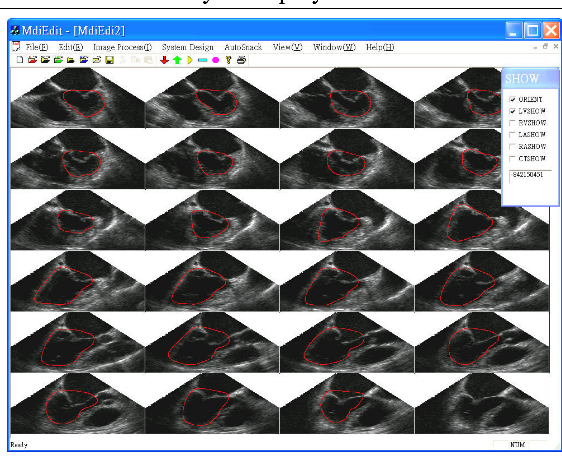

Figure 1. Illustration of auto-delineated LV

3. Results

The result for the auto-delineated LV chamber using prior information was shown in Figure 1. The result of developed software system was shown in Figure 2. As illustrated, the figure was showing the self-developed software system with the wire-frame model of the left ventricle and three cutting planes. These images were reconstructed for visualization and parameters calculation. Three axial (x, y, and z axis) cut slice views of LV with delineated contour were provided to examining the correctness of auto-delineation.

The volume calculation of left ventricle was using

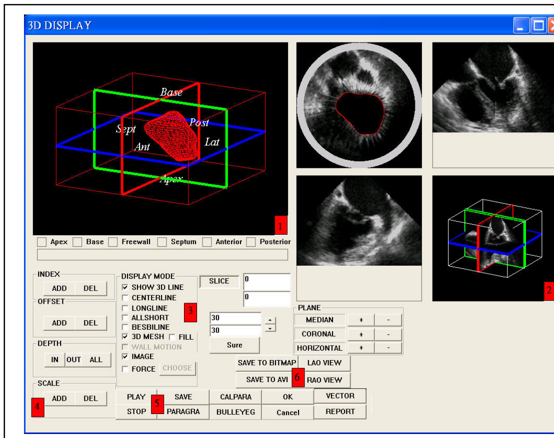

Figure 2. The developed software analysis system showing wire-frame model and three cutting plane of LV.

Simpson's rule. The result of volume calculation was showing as Figure 3. Then, the stroke volume (SV) and the Ejection Fraction (EF) could be calculated. For the given example, the end-diastolic volume was 144 ml. And, the end-systolic volume was 90 ml. The stroke volume is 54 ml. The Ejection Fraction is 37%.

For the purpose of the cardiac shape and the strain analysis, the floating long axis of LV was reconstructed from the centroid of z-view contour of each LV image. From the collected data, the displacement of centroid among the time frame could be ignored as demonstrated in Figure 4. In tracing the normal vector of contour and centroid of LV chamber, the distribution of centroid appeared in a function of natural logarithm decay which was significantly distributed within the radius of 1 mm. The normal vectors of contour were also calculated at their finest resolution. The distribution angle for normal vectors was tallied. The peak of the normal vectors distribution was within ±6°. This data implied that each contour could be segmented into 30 sections. Therefore, for the surface of LV chamber, the total of 900 blocks could be analysis. The effected size of dysfunction area could be carefully observed is 0.25 cm^2 for 5 cm diameter size of heart. This means that the dysfunction of local area, such as LAD area of myocardial can be examined using reconstructed 4D LV model using TEE images. These results also indicated that the motion of reconstructed LV could be examined as continuous movement.

The effective Radius (ER) of LV chamber was then calculated from the distance between the delineated LV contours to the LV floating long axis. The result of extracted ER was shown with the bull-eyed movie display. One of resulting bull-eyed display of ER with derivative (ER with time difference) was showing in Figure 5. The selected derivative ER shown in this figure

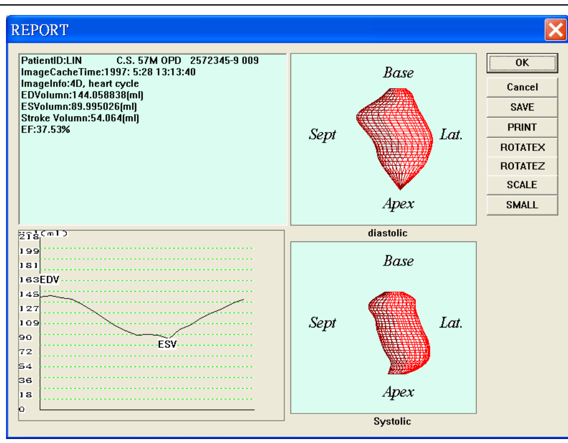

Figure 3. One of report system showing calculated LV volume.

was at the phase of early relaxation at time frame 11 and 12. The brighter color in the bull-eyed display indicates the higher radius and lighter color means shorter radius. For this given example, at early diastolic phase, the derivative ER of bull-eye display was showing that the mid-level of anterior and septum recoiled first.

The calculated shape for the contraction and the relaxation and the strain parameters were display with the LV model as shown in Figure 6. As shown in the figure, the value of curvature was displayed with LV model. The dark color (dark green) was indicating the large value of curvature. The light color (light green) was indicating the small value of curvature. The left panel was LV model at end diastolic phase. The right panel was LV model at end systolic phase. One could clearly identify that at end systolic phase, the curvature at apex was larger than end diastolic. The parameters related shape analysis not shown here were the regional and the global curvature for the wall motion analysis, the effective R-ratio of the myocardium and the chamber, the area surface curvature, global surface curvature circularity and many other calculations.

4. Discussion and conclusions

The self-developed software system was designed to analyze a gated and continuous motion imaging data set. The data demonstrated in this article were using trans-esophageal echocardiogram with 90 viewing angles and 33 frames pre second. The LV functional parameters extracted were the stroke volume (cardiac output), eject fraction (EF) and many others. The LV morphological parameters were wall motion analysis, LV chamber

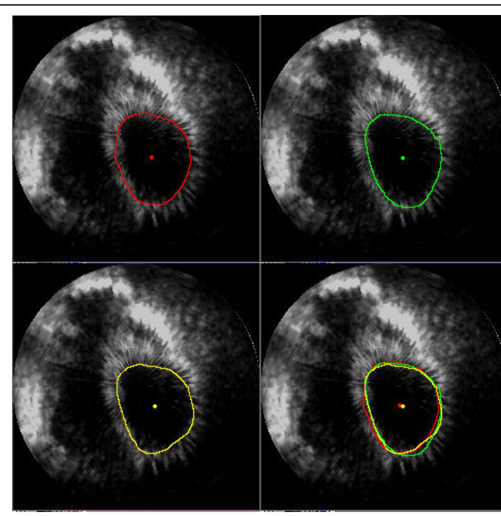

Figure 4. The illustration of centroid for three consecutive frames.

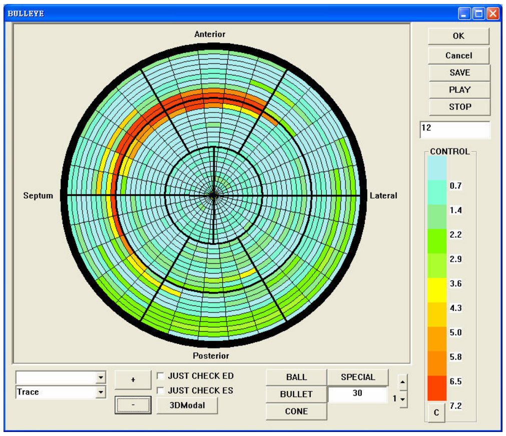

Figure 5. The bull eyed display for the derivative ER

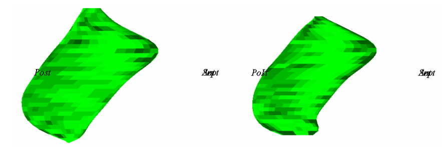

Figure 6. The value of curvature displayed with LV model

cavity variation, effective R-ratio of myocardium and chamber, area surface curvature, global surface curvature circularity calculation. The developed system was also programmed including functions that displayed the cardiac images of Echocardiogram with movie; that semi-automatic traced the LV contour; that would be reconstructing 3-D of LV model; that would be analyzing and visually display morphological and functional parameter onto LV model. The reported system also would provide the display functions of (1) echocardiogram TV-wall display; (2) 3-D wire frame and visualized model of LV.

Using reconstructed non-invasive dynamic cardiac image to evaluate global cardiac performance and details of myocardium activities will be significant both to the patients and to the doctors. This article described the methods and the process of finding the physiological functions and the shape parameters. These parameters could be used in studying the functionality of left ventricle, the status of abnormality of myocardial, the geometric and morphological of Left ventricle in shape analysis. These data can also be used in modeling the LV function and the myocardial motion. The synergetic evaluation the details of myocardial activities in adequate resolution can significantly improve the ability to localize the area of dysfunction non-invasively.

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