A Validation Study of Left Ventricular Contraction and Relaxation Model

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Abstract

This study modeled the Left Ventricular (LV) motion using parameters of myocardial twisting angle and shortening of LV long axis. Twenty two sets of the heart's volume-time curve (VTC) were analyzed. The ejection fraction (EF) of each data set was evaluated. The average of EF was 70.96±5.76%. The accuracy of model simulation was evaluated in each time frame. The average difference of volume between simulated LV and 4D cardio real images was 2.92±3.09(ml). The correlation of simulated LV volumes to the 4D real cardio images was 0.93. The average difference short axis radius of each time frame in the cardio cycle was 1.55±0.47(mm). This result has shown that the LV motion could be modeled using the function of shorten LV long axis and the function of the myocardial twisting angle.

1. Introduction

Multiple Slice Computer Tomography (MSCT) Cardiac Images have become the major methodology for evaluating myocardial and ventricular function. For example, the Ejection Fraction could be accurate evaluated [1]. Observations could be made before, during, and after exercise and stress. Such procedure creates myocardial perfusion dysfunction and corresponding wall motion abnormalities in regional ventricular wall supplied by critically stenosis coronary arteries. There were numerous models that were used to evaluate the deformation of LV [2-4]. Yet, the function of ventricle and property of myocardium are still to be identified. The modeling will enlighten the complexity of LV motion, and, provide clinical applications.

To reconstruct 4D view of beating heart model using MSCT cardiac images is complicated. However, the 4D view of beating heart may be useful in diagnosis. The study was using 10 phases of MSCT cardiac images to model the dynamic 3D left ventricle that is reconstructing a 4D view of ventricle. Furthermore, functional parameters extracted from volume-time relationship will be extracted from the model for evaluation of ventricular function and the motion of ventricle.

In this study, the motion and the deformation of ventricular shape were modeled using the spiral function that was governed by two equations. The periodic function of shortening and lengthening of the ventricular long axis was modeled using information extracted from reconstructed MSCT cardiac images. The motion of thickening of myocardium in contraction and thinning the ventricular wall in relaxation was modeled using spiral function [5] to model of ventricle wall in contraction and relaxation to emulate the motion of wall thickening and thinning.

2. Methods

A self-developed program with a user friendly interface was integrated as an image processing tool for analyzing 4D cardio CT image data set. The program was developed in visual C++ 6.0 that runs on window XP operating system. The 3D reconstruction and the left ventricular function analysis, such as Volume-Time-Curve (VTC) and Ejection Fraction (EF), were able to use a minimal user interface in extracting the contour information.

The CT images were recorded in DICOM format. The cardio images data set at each time frame will be reading into the processing system. Then, a 3D cardio image will be reconstructed and displayed for inspection and further process. There were 10 time frames of 3D cardio images for each data set (gated by ECG, see Figure 1). Each 3D reconstructed cardio models were re-aligned and re-sampled to the short axis view and ready for contour extraction, as shown in Figure 2. The contour information will be used in the reconstruction of 3D wire mesh view display, volume calculation and wall motion analysis.

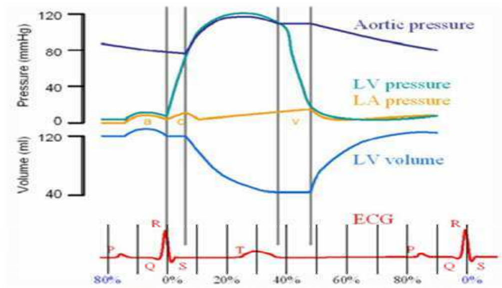

Figure 1. The R-R interval in relation to the percentage of cardiac cycle.

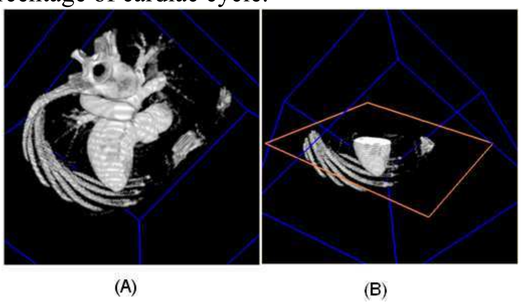

Figure 2. 3D reconstructed cardio model. (A) raw data 3D reconstructed cardio view. (B) long axis re-alignment for short axis re-sampling.

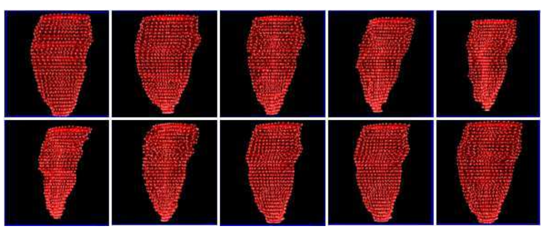

Figure 3. The reconstructed 10 time frame wire-frame model.

The LV 3D contours were extracted from mitral valve to the apex. The LV endocardial contour was delineated using seed region growth method and B-Spline [6]. The information of the delineated endocardial contours was used to reconstruct 3D cardiac model using Triangular mesh method [6-8], as shown in Figure 3.

The quantified data resulted from 4D volume reconstruction were the Volume-Time relationship, the Ejection Fraction, radius of LV chamber, the time relationship to the length of long axis.

The function of the myocardial twisting angle was derived from the LV time-volume curve. It is the function that is reciprocal of volume-time curve, shown as the red line in Figure 4. The total angle change will be up to 20° [5]. The function of the shortening of long axis was derived from actual 4D cardio images, as shown in Figure 5.

The cylindroid helical-coil and Archimedean spiral model which were using the function of myocardial

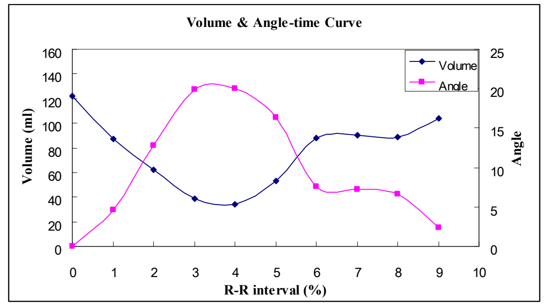

Figure 4. Volume time curve and Angle time curve

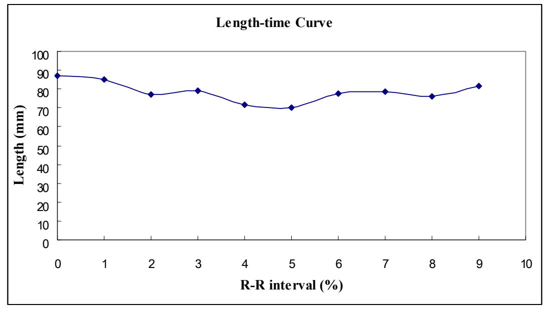

Figure 5. Long axis shortening time curve.

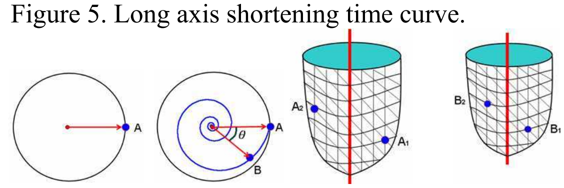

Figure 6. On the left, the Archimedean spiral model for twisting motion of myocardium. On the right, the cylindroids helical-coil model for 4D motion simulation.

twisting angle and the function of shortening of LV long axis to simulate the LV motion, as shown in Figure 6.

The simulated data were checked against original data. The volume difference in each time frame and data set was evaluated. Thirty sample points of radius per re-sampled image slice were evaluated. The results were checked against the original contours information.

3. Results

To validate the functional model of ventricle, the time-volume curve was compared in twenty-two 4D data set. The accuracy of model simulation was evaluated in each time frame. The correlation of simulated LV volumes to the 4D real cardio images was 0.93. The average difference of volume between simulated LV and 4D cardio real images was 2.92±3.09(ml). As shown in Figure 7, the top panel was a correlation of individual data set. The regression slope was 0.86 and R2 was 0.95. The bottom panel was showing the total volume correlation. The regression slope was 0.87 and R2 was 0.93.

The validation of the left ventricular contraction model was further checked against the volume time curve of the patient's data. The ejection fraction (EF) of each data set

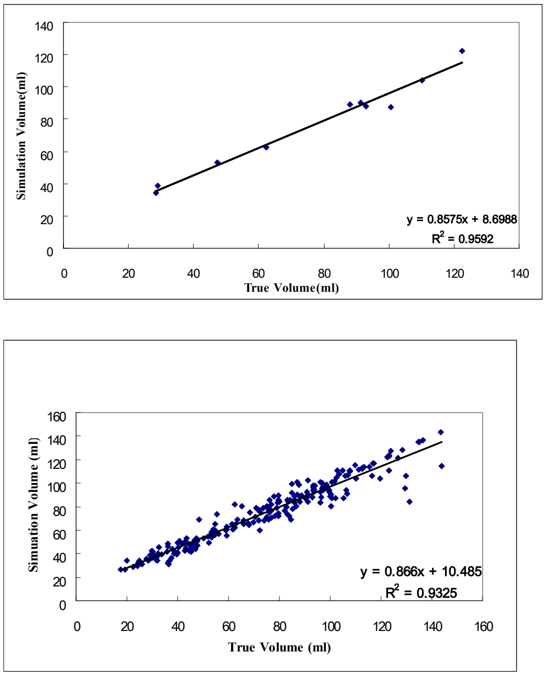

Figure 7. The result of simulated LV volume was compared to the actual data. The top panel, it is a result single data set. The regression slope was 0.86 and R2 was 0.95. The bottom panel, it is the data comparison of 22 data sets. The total volume correlation was showing that the simulated data is closely agree to the actual data. The regression slope was 0.87 and R2 was 0.93.

was evaluated. The average of EF was 70.96±5.76%.

These results illustrated that the method of simulating model was accurate predicting the size of LV volume in each time frame for each data set.

To further illustrating the accuracy of simulation, the volume difference in systole and diastole were evaluated. The result showed that the average different of the ejection volume between simulated data and actual data was 5.2±0.5 c.c. along the contraction of the heart beat. The difference of the filling volume was average of 7.96±2.89 c.c. along the relaxation of the heart beat. These results showed that modeling the motion of left ventricular contraction is more accurate than modeling the motion of relaxation.

For the volume difference among time frame, as shown in Figure 8, the blue curve was the actual image data. And, the red line was the simulated data. In this figure, the average volume change for simulated data was closely following the change of actual data in each time frame. There was only one deviation at time frame 2.

For the shape analysis, as shown in Figure 9, the radius of each image slice was analyzed in 30 sample points. The average difference of radius was less than 2 mm. The figure was showing the simulated LV shape was closely tracking the shape of original LV chamber.

4. Discussion and conclusions

In this study, we have shown using the myocardial twisting function and shortening of long axis can accurately simulate the LV function. The volume at each time frame and for each simulated data set was closely followed. The LV shape and shape change were closely tracked by the simulated model. These results have shown that the LV motion could be modeled using the function of shorten LV long axis and the function of the myocardial twisting angle.

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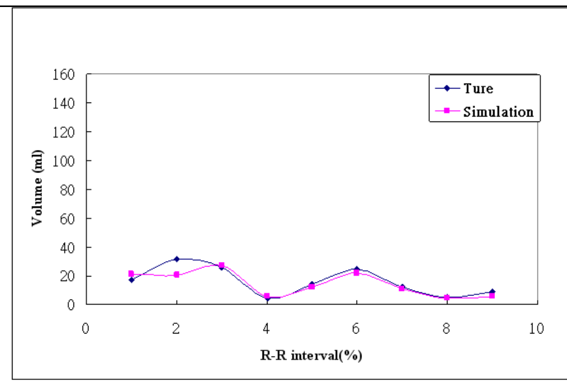

Figure 8. The volume change among the time frame. The red curve was simulated data and the blue line was actual data. This figure was showing the simulated data was closely following the change of volume in each time frame.

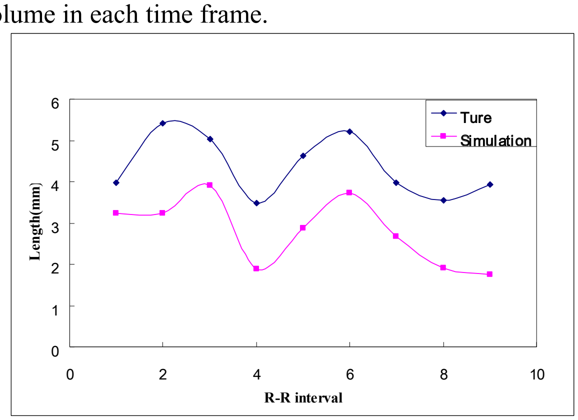

Figure 9. The average radius difference between simulated data and actual data. The figure was showing the simulated LV shape was closely tracking the shape of original LV chamber.

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