Visualization of a Motility Analysis for the Gated Myocardium Images

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Abstract

Cardiologists assume that analysis of the motion of the heart (especially the left ventricle) can give some information about the health of the myocardium. We applied the myocardium model in a gated myocardium SPECT image that showed a cardiac biochemical reaction, and analyzed the motility between the gated myocardium SPECT image and the myocardium model. We constructed a left ventricle myocardium model and mathematically evaluated the motion of the myocardium. The myocardium model was created based on four-dimensional transformation. We then analyzed a regional motility direction and size of the gated myocardium SPECT constructed on a fitting model.

Key words: Four-dimensional transformation, Left Ventricle, Myocardium gated SPECT, Perfusion

1. Introduction

Cardiologists assume that analysis of the motion of the left ventricle can give some information about the health of the myocardium. We applied the myocardium model in the gated myocardium SPECT image that showed a cardiac biochemical reaction, and analyzed the motility between the gated myocardium SPECT image and the myocardium model. The equipment can make continuous images which can be used to make the three dimensional cardiac motion through cardiac cycle similar to a three dimensional cine. Four-dimensional imaging techniques that add the time to three-dimension space can be used to analyze cardiac motion, since we live in a real world. We analyzed the motility of the left ventricle myocardium using gated myocardial SPECT images. We used gated SPECT images which were gained from subjects with known or suspected ischemic heart disease, and normal cases for experiments. We made the parameterized super-quadric model using global parameter functions for analyzing the gained gated SPECT images [1]. We estimated the motility of the left ventricle myocardium and displayed the measured motility, myocardial thickening and the contractility of myocardium to the surface of the model.

2. Modeling Methods

Table. 1 describes the camera-ready paper format for the ICAT. The standard paper size is ISO A4 paper. However, you may use Letter size paper with margin parameters in Table. 2. The camera-ready paper will be printed in original size. If you do not have "Times New Roman" font, you may use similar fonts. Logo marks should appear on the top-right corner of the first page.

A. *The parameterized super-quadric modeling*

Firstly, we constructed a left ventricle myocardium model and mathematically evaluated the motion of the myocardium. Secondly, we made a hybrid-ellipsoidal model using the parameterized super-quadric ellipsoidal model [1].

$$P = h_0 w \begin{pmatrix} h_1 \cdot \cos u \cdot \cos v \\ h_2 \cdot \cos u \cdot \sin v \\ h_3 \cdot \sin u \end{pmatrix} \qquad (1)$$

where

$-\frac{\pi}{2} \le u \le \frac{\pi}{2}$, $-\pi \le v \le \pi$, $w > 0$, $h_0 > 0$,
$0 \le h_1, h_2, h_3 \le 1$.

The super-quadric ellipsoidal model can be deformed into the model which we want as changing the parameter value. The parameter h_0 is a scaling factor which determines the whole, in which determines the axis size. These parameters are called model sizes. The parameters h_1, h_2, h_3 are scaling factors that determine the axis size. These parameters are called global parameters. We generated the model which was able to estimate the motility of the left ventricle myocardium. It also has a similar form, therefore, we added the parameterized model functions such as the global parameterized values to it.
The model can be divided by four movements; the fore and back movements on the x-axis, right and left movements on y-axis, top and bottom movements on z-

axis, and twist motions. Because of the similarity of the movement on each axis, it has a form similar to parameterized functions which deformed the model:

$$\begin{aligned} c_1 &= r_x \cdot \cos(t/2 - a_1) + s_x \\ c_2 &= r_y \cdot \sin(t/2 - a_2) + s_y \\ c_3 &= r_z \cdot \sin(t/2 - a_3) + s_z \end{aligned} \qquad (2)$$

where $0 \le r_x, r_y, r_z \le 0.2$, $0 \le s_x, s_y, s_z \le 1.0$, $-\infty \le t \le \infty$, $-\pi/2 \le a_1, a_2, a_3 \le \pi/2$.

The parameters r_x, r_y, r_z are the movement on x-axis, y-axis and z-axis. They are the scaling factors which determine the degree of deformation in the parameterized super-ellipsoidal model through time *t*. The parameters s_x, s_y, s_z determine the size of model. Therefore, if a profit value of parameter r and s is input to an equation (2) over time *t*, the function *C* represents the movement of the left ventricle in the cardiac cycle on each axis. The parameters a_1, a_2, a_3 display a phase's change in a motion of the periodic left ventricle. The parameterized functions c_1, c_2, c_3 correspond to the parameterized values h_1, h_2, h_3 in equation (1).

The values which are produced from Equation (2), the parameterized functions c_1, c_2, c_3 are used to represent the twist motion of the left ventricle. Thirdly, the twist motion is different from the previous motion, such as the contraction and relaxation: the equation which represents the twist motion is also composed of a sinusoidal function which has little complexity. Equation (3) represents the twist motion.

$$\begin{aligned} T_1 &= c_1 \cdot \sin(t_f \cdot \sin(\tau \cdot t) + u) + c_2 \cdot \cos(t_f \cdot \sin(\tau \cdot t) + u) \\ T_2 &= c_1 \cdot \cos(t_f \cdot \sin(\tau \cdot t) + u) + c_2 \cdot \sin(t_f \cdot \sin(\tau \cdot t) + u) \\ T_3 &= c_3 \end{aligned} \qquad (3)$$

where $t_f > 0$, $\tau \le 1, -\infty \le t \le \infty$, $-\frac{\pi}{2} \le u \le \frac{\pi}{2}$

A value of t_f is the twist factor which represents the twisting degree of the left ventricle. A value of τ is the factor which can be used to correspond to the heart beat ratio. When we apply this case to the twist motion, the contraction of the left ventricle represents the higher gradient value because of the requesting of a large force of myocardium in a short period of time.

B. Visualization parameters and functional methods

1) The myocardial thickness

The myocardial thickness among parameters to diagnose the cardiac disease can be used as an important factor to diagnose the myocardial infraction [2]. However, the thickness represented by the count has difficulty of diagnosis and the regional thickness is not analyzed at a glance. Therefore regional myocardium thickness represented by numerical values was displayed by a color table which was applied to the model surface.
In order to yield the thickness of the myocardium, we used a super-ellipsoidal model that is extended from a super-quadric model. In the super-ellipsoidal model, we used not a whole ellipsoidal model but a partial ellipsoidal model truncated in the basal area. In equation (1), the extent of u is changed to the value from $-\pi/2$ to $\pi/6$. We divided a partial ellipsoidal model into 32 slices from the apex to the basal of the end of the partial ellipsoidal model. Each slice was divided into 36 partial regions by $10°$. Therefore the surface of a partial ellipsoidal model was composed of 1152 plates.

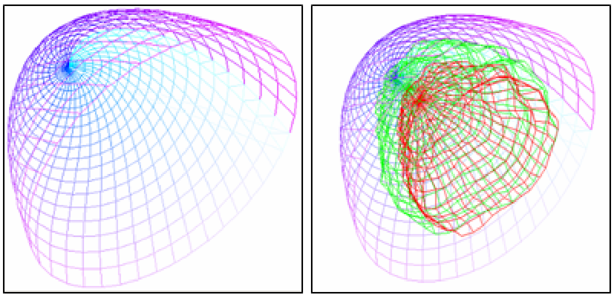

Fig. 1. (a) The super-ellipsoidal model, (b) The cardiac model in the super-ellipsoidal model.

2) The motility

To estimate the motility of the myocardium, we generated the parameterized super-ellipsoidal model and calculated the fitting model using the model and the endocardial contour. We used an interpolation between two features to create the fitting model. We used the LSF (least square fitting) algorithm for interpolation between the parameterized super-ellipsoidal model and the endocardial contour [3]. In the following we present an algorithm to formulate the fitting model.

i. Finding the framework in relation to the two features. We selected the long axis (z-axis) in the Cartesian coordinates where the center of the two features were set. In order to analyze the complex motion, such as a twist, we selected the long axis through the center of the two models.
ii. Finding the basal of the super-quadric model where the basal of the reconstructed cardiac model coincides with. This process needs to estimate the movement on the z-axis.
iii. Dividing the slice into 36 pieces [4].
iv. Creating the fitting model using the LSF as Fig. 2.

3) New functional parameter representation: contractility

The gated myocardial SPECT provides a volume curve for the left ventricle central pressure curve, which could be estimated with radial artery: a tonometrically measured radial arterial pressure curve can provide a systolic pressure curve for the left ventricle.

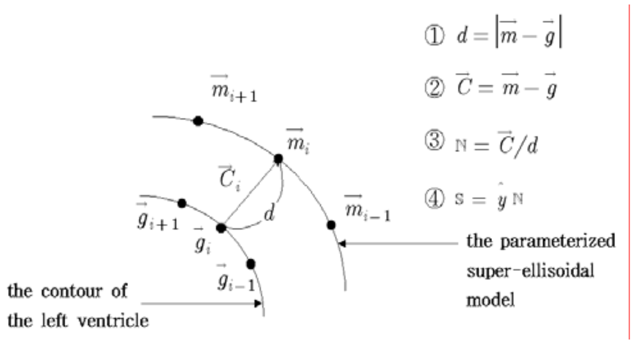

Fig. 2. Creating the fitting model of the contour of left ventricle in gated myocardial SPECT image

Left ventricle contractility and mechanoenergetics could be assessed by these indices; Maximal elasticity (E_{max}: maximal ratio of pressure over volume) of the left ventricular myocardium obtained from time-varying elastic curves represents myocardial contractility, which is independent of preload and afterloads. Suga calculated E_{max} by interpolating end-systolic points of multiple pressure-volume loops (*PV* loop) obtained invasively by varying the preload induced by an inferior end-systolic pressure-volume loop that had been used as a load-independent measure of the left ventricular contractility.

With these 2 noninvasive methods, a single systolic *PV* loop can be obtained. A time-pressure curve and time-volume curve are the two fundamental physical variables to describe the mechanical properties of the left ventricle. A non-invasive method of quantifying myocardial global contractility using a single systolic *PV* loop was developed by Senzaki *et al.*, and extended by Lee *et al.*, by measuring a time-volume curve using gated myocardial SPECT [5]. Since these previous methods provide only the overall contractile function of left ventricle, we developed a method to quantify the regional contractility of the myocardium [5].

3. Results

The model was used as a tool to estimate the myocardial thickness and motility in Fig. 3. Using the regional changes obtained by tonometry, we computed the regional contractility of each segment.

We made an experiment on analyzing the motility of the left ventricle myocardium. The criterion was tested in the validation study of 7 normal subjects and 26 patients with prior myocardial infarction. In order to analyze the motility, we used both the mean and the variance of the total motion during the cardiac cycle. The average of the normal subject is 0.46 and a variance is 0.02. In the case of the patients, the average and variance of motility was 0.59 and 0.08 respectively.

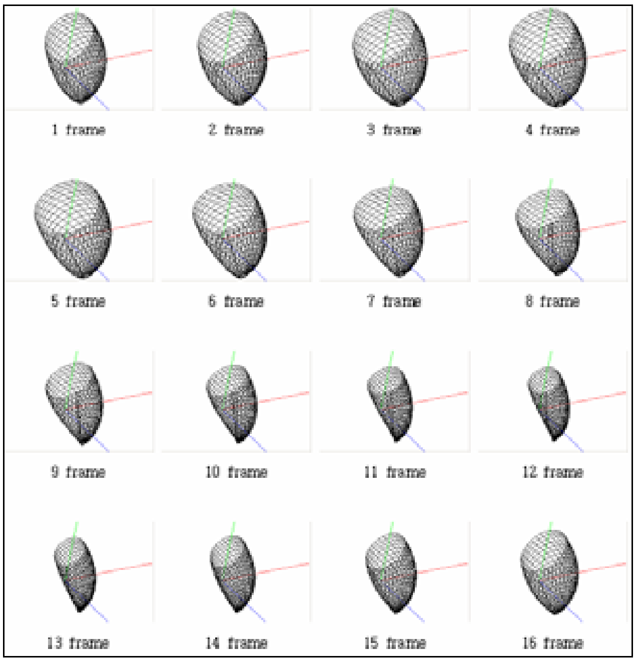

Fig. 3. The form of model in each frame.

Although, the average value did not have the difference between the normal and abnormal, the variance was within them. In general, patients were 0.08 and normal subjects were 0.02 in variance.

4. Conclusion

Cardiologists assume that analysis of motion of the left ventricle can give some information about the health of the myocardium. We have constructed a left ventricle myocardium model and mathematically evaluated the motion of myocardium. The myocardium model was developed based on four-dimensional transformation. The four-dimensional transformation is defined to describe the left ventricle (LV) motion and a method is presented to estimate it from sequences of the three dimensional super-ellipsoidal model, that was using the sinusoidal function. The measured count for thickening was changed as time frames in this model.

The motility was parameterized additionally within the parameterized super quadric model. The difference between the normal and abnormal subject was estimated. We expected that this model distinguished between normal and abnormal subjects. An exact analysis of momentum utilizing this model could be evaluated.

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