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Construction of Personalized Heart Models from MRI Images

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Abstract

A semi-automatic algorithm is proposed for construction of personalized heart model from Magnetic Resonance Imaging (MRI) images, emphasizing on applications to cardiac electrophysiological simulation. The physiological characterizations of personalized heart models were set in the same way as the Wei-Harumi model. For validation, 12-lead electrocardiograms (ECG) were simulated with a model of normal heart. The results show good agreement with clinical findings. This study suggests a new direction of electrocardiological forward problem and application in whole-heart modeling.

1. Introduction

In the previous work of the author's group, a state-of-the heart model (Wei-Harumi model) had been developed to simulate the body surface electrocardiogram (ECG) based on anatomical and electrophysiological settings in a whole heart level [1, 2]. This model is, however an averaged model reconstructed from typical anatomical data. For basic studies in the future and possible applications to "personalized medicine", it is necessary to take into account the personalization for heart modeling. The purpose of this study is to incorporate correct shape of special individuals in heart modeling, and to transform the shape model to discrete heart model, and a model with electrophysiological settings for computer simulation of Electrocardiograms. In the following sections, we first introduce semi-automated procedures for creation of realistic-shaped heart based on MRI image database, and describe the way to transform the shape model into a boundary surface model, and then a discrete volume model. We then introduce the electrophysiological settings for the discrete volume model. Finally, we present simulated ECGs for validation.

2. Methods

Images of healthy volunteers were acquired using a 1.5T GE CV scanner (GE medical systems, Milwaukee) at Southern Northeast General Hospital at Koriyama, Fukushima, Japan. Image data for each subject consist of 30 short axial slices (1.5 mm thick,) with a transversal spatial resolution of 1.5mm.
To construct the personalized heart model from the MRI images, we first extracted contours of epicardium and endocardium by applying the SNAKES algorithm [3], and then interpolated the extracted contours using the β-splines. Next, we applied the shortest-diagonal method to generate triangle surface meshes [4]. Fig. 1(a) shows boundary representation (B-rep) of the realistic-shaped heart model based on the above procedures. For computer simulation, the shape model has to be transformed to a discrete volume model in 3-dimentions (3D). For computer simulation, the discrete volume model is made using the same spatial resolution with the Wei-Harumi model. For this purpose, the shape model is set in the closest packed lattice with 56×56×90.Then each lattice is detected to be either inside or outside of shape model. If four points, $A = (a_x, a_y, a_z)$, $B = (b_x, b_y, b_z)$, $C = (c_x, c_y, c_z)$,

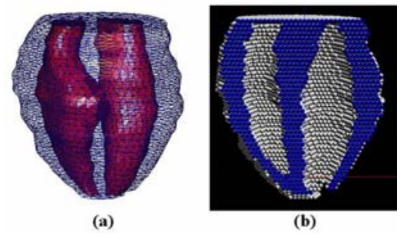

Figure 1. (a) Cardiac shape model (b) Unit division model.

and $D = (d_x, d_y, d_z)$ are given, the $ORIENT3D$ [5] is defined as follow.

$$ORIENT3D(A, B, C, D) \\ = (A - D) \cdot ((B - D) \times (C - D)) \quad (1)$$

D is above the plane defined by a triangle ABC when the $ORIENT3D(A, B, C, D) < 0$. D is under the plane ABC when the $ORIENT3D(A, B, C, D) > 0$. if the $ORIENT3D(A, B, C, D) = 0$, four points are coplanar. Fig. 1(b) shows the developed discrete volume model. The electrophysiological settings are made manually by referring to the Wei-Harumi model, where there are seven regular cardiac cell types such as sinus node, atria, atria-ventricular node, His bundle, bundle branch, Prukinje fiber, and ventricles. The excitation and replolarization processes of model were simulated, and electrocardiographic potentials on the body surface of torso model were simulated in the same way as [1, 2]. The positions of model cells were repeatedly adjusted until simulated results, such as excitation isochrones, vectrocardiogram, surface ECGs, fall within the normal range of clinical data.

3. Results

The 12-lead ECG is considered the easiest way to confirm the simulation results. In Fig. 2, the 12 lead ECGs simulated with the model of normal heart is shown. We used the Cardiomaster [1] for the simulation. It is confirmed that the ECG waveforms in Fig. 2 were within normal range.

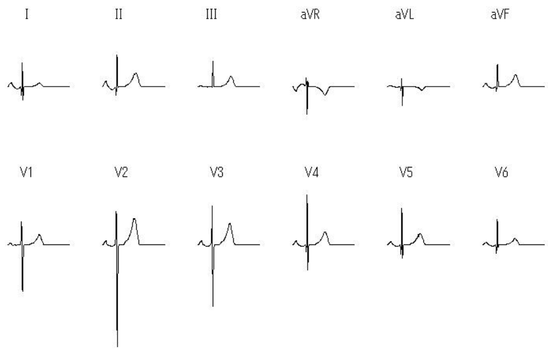

Figure 2. Simulated 12-lead ECG.

4. Discussion and Conclusion

In this paper, the study on construction of personalized heart model is reported. This study is an extension of the Wei-Harumi model in order to incorporate personalized cardiac shapes. As a result, semi-automatic procedures are developed for computer simulation with personalized heart models. The simulated 12-lead ECGs show that close results can be obtained with a normal heart model as the Wei-Harumi model.

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