An MRI-based Beating Heart Model

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Synopsis

In this report, we use cardiac MRI to generate a personalised electrical heart model so as to investigate the cardiac electrical activities and its resulting body surface Electrocardiographic (ECG) potentials (BSPM). The BSPM and endocardial potentials can then be used for the detection of life threatening cardiac arrhythmias and other heart diseases. In our study, we construct a beating heart model based on our segmented myocardial contours from multiple-slice MRI time sequences. The moving heart model is then situated inside a MRI-based electromagnetic human torso model. The ECG simulations demonstrate that the inclusion of heart motion is essential to accurately model surface potentials.

Method

A semi-automated contour detection algorithm has been developed to recreate a moving bi-ventricular heart model, followed by a creation of a special conduction system inside the heart model. Eventually we model the cardiac source using equivalent moving dipoles and calculate the resultant body surface potentials.

Image Acquisition: MRI datasets are acquired from six subjects during routine clinical appraisal. Imaging is performed on a 1.5 Tesla Signa Twinspeed system with a four element cardiac phased array coil. Cine MR Images are obtained using SSFP acquisition. ECG R-wave triggering with k-space segmentation of 16 views per segment was used during breath-hold. 20 cardiac phases per slice location are reconstructed resulting in 20-by-*m* short-axis images (*m* slice locations) and 20 vertical long-axis images at a single slice location. The long-axis plane is doubly oblique and is manually positioned to lie along the medial axis of the left ventricle (LV). For each interval we have one slice in vertical long-axis orientation and *m* slices in short axis orientation, where *m* varies from 8 to 10 according to the size of the patient's heart. Data of one patient is currently exported for the ECG imaging study.

Contour Extraction**:** Globally optimal geodesic active contour (GOGAC) algorithm [1] is used for the myocardium contour detections. The process begins with the segmentation of the left endocardium in a single short-axis slice, typically during the end-diastolic phase and positioned towards the mid-plane between the atrium and ventricular apex. To segment this slice, a single point may be placed inside the LV endocardium, the GOGAC algorithm is then applied to extract its boundary. Following the segmentation of a single slice, this segmentation may be extrapolated to all short axis slices containing the LV. In addition to the short-axis slices, one or more long-axis views may have been acquired during setup. These long-axis views are used to estimate the extent of the LV and therefore plan the positioning of the short-axis planes. We may segment the LV lumen in the long-axis plane. The segmentation method for the long-axis slices is identical to that for the short-axis slices. Following the segmentation of the LV endocardium, the LV epicardium and septal wall may be extracted either automatically or semi-automatically. After segmenting the LV contours the right ventricular (RV) endocardium may be extracted. On the RV segmentation, it makes use of the LV myocardial segmentation to track the septal wall and provide further guidance to the RV segmentation. A dedicated user interface and image processing platform is designed for the implementation of the contour detections. Fig.1 illustrates the contour extraction and reconstructed heart model.

Fig.1 Extraction of the myocardium contours and reconstruction of the moving heart model

Special Conduction System Setup: The special conduction system (SCS) of the heart is obtained from an existing SCS model [2]. We deform a previously developed static heart model [2] to match the new heart geometry and then attach the SCS to obtain a similar activation sequence in the new heart model. The deformation is based on a stable regularization procedure.

Cardiac Electric Source Modeling: After the SCS is incorporated into the heart model, we modify a dipole-based static electric source modeling algorithm [2] to the moving heart model. The fiber structure has been considered for the determination of the activation sequences over the myocardium wall, the dipole currents in each cardiac element is the source of the cardiac field.

Calculation of Body Surface ECG Potentials: In the simulation, the heart model is mounted in a 2mm resolution MRI-based human model (NORMAN). To calculate the torso surface ECG potentials generated by the moving cardiac sources, the governing equation may be expressed as $\nabla(\vec{\sigma}\phi) + f = 0$ where ϕ represents the potential function, $\vec{\sigma}$ the conductivity tensor and f the current density source. In this study the finite-volume formulation was chosen to solve the forward problem.

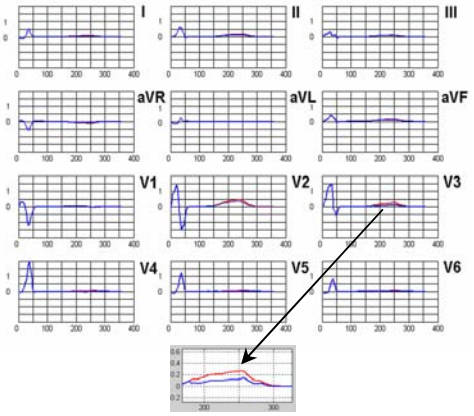

Fig.2 Simulated 12-lead ECG signals (red:static model;blue:beating model)

Results

The traditional modality for visualizing the heart's electrical activity is the 12-lead ECG. Here we compare the ECGs (see Fig.2) generated from the moving heart and in the same heart at rest. The static heart ECG takes on the shape of the moving heart from the time of the Q-wave. The two simulations are remarkably similar during the QRS interval. This is because the QRS complex corresponds to the isovolumetric contraction phase during which the heart is in a relatively static state and deforms very little from its resting state. During the T-wave however, when the ventricle is at peak contraction, differences are apparent in the ECG signals on several leads. Body surface potential maps (BSPMs) provide an alternative viewpoint to the ECG. From the simulation we took snapshots of the BSPMs at 30ms and 240ms after the onset of activation. These times correspond approximately to before and after ventricle contractions. From the BSPM comparison shown in Fig. 3, it can be seen they are quite similar at early stage in ECG period and then differ later, shortly before the peak of the T-wave. The difference could be critical for the study of the well-known ill-posed cardiac inverse problem. The results are in agreement with the ECGs in Fig. 2 and reported results in the literature [3].

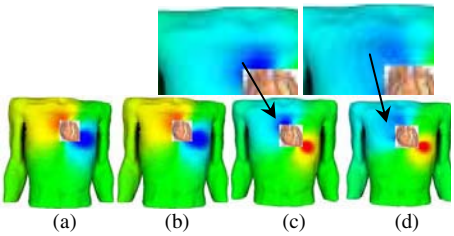

Fig.3 Body Surface Potential Maps at 30ms (a,b) and 240ms(c,d) after the onset of activation in the ventricles.(a,c):static model;(b,d): dynamic model.

Conclusion

In this report, a macroscopic electrical heart model has been constructed using MRI-based biomechanical information. The simulations show that the use of a moving heart may produce more realistic ECGs and BSPMs. The fusion of the MR structure imaging and cardiac electrical functional imaging will enable the assessment of various functions of the heart. The coupling of these two imaging techniques in time and space permits the evaluation of the electrical function more accurately, which would allow imaging of complex and life threatening arrhythmias.

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