Patient-Specific Identification of Optimal Placement of Ubiquitous ECG using a 3D Model of Cardiac Electrophysiology

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Abstract

As the era of ubiquitous healthcare begins, many conventional medical devices are being redesigned for ubiquitous healthcare purposes. Recently, a bipolar mini-electrocardiogram (U-EKG) for ubiquitous healthcare has been introduced, and various studies using the U-EKG device are in progress. Because it has two electrodes in a small area of the torso surface, the U-EKG requires an optimal design that is suitable for detecting EKG signals. Using a multi-scale model of cardiac electrophysiology (Figure 1), we have developed a simulation method for identifying the optimal attachment position and direction of U-EKG electrodes on the torso surface. To construct a patient-specific model, the size, location in the torso, and heart axis of a standard heart model were adjusted to match those of a patient's heart obtained from clinical CT images (Figure 2). Next, we simulated the heart-torso model to obtain a body surface potential map (BSPM) and EKG waveforms, which were compared with the patient's measured data. Using the model, we obtained the optimal positions of two U-EKG electrodes, spaced 5 cm apart, for detecting the P, R, and T waves. For the validation of the model, the morphology of the pseudo-EKG waveforms were compared and matched well with clinically measured data (Figure 3). The EKG data, computed at the optimal placement of the U-EKG for a specific wave, showed a clear shape for the target wave, but equivocal shapes for the other waves (Figure 4, 5). The present study provides an efficient simulation method to identify the optimal attachment position and direction of the U-EKG electrodes on the torso surface of a patient.

Key Words: Optimal Design, Ubiquitous electrocardiogram, Simulation method

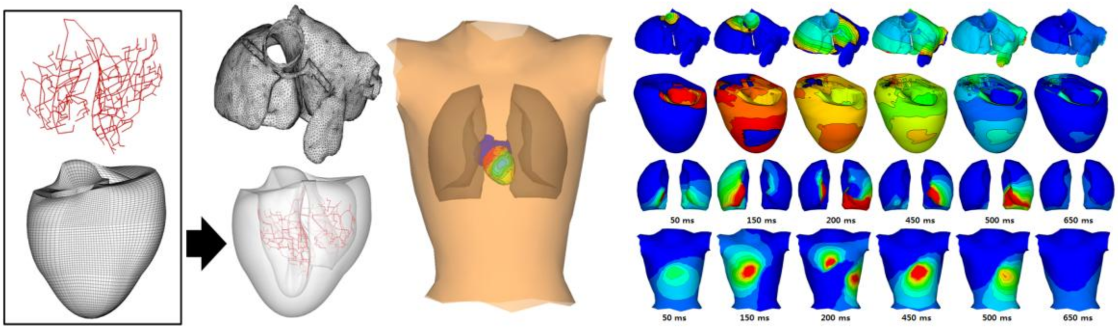


Figure 1 Computational model of heart including the Purkinje network, ventricle, atria, and torso. 504 linear elements for purkinje network, 120,000 hexahedron elements for ventricle, 202,232 tetrahedron elements for atria, 14,221 triangle elements for torso, and 558 triangle elements for lung. Isopotential maps of atria, ventricles, lung and torso (right panel).

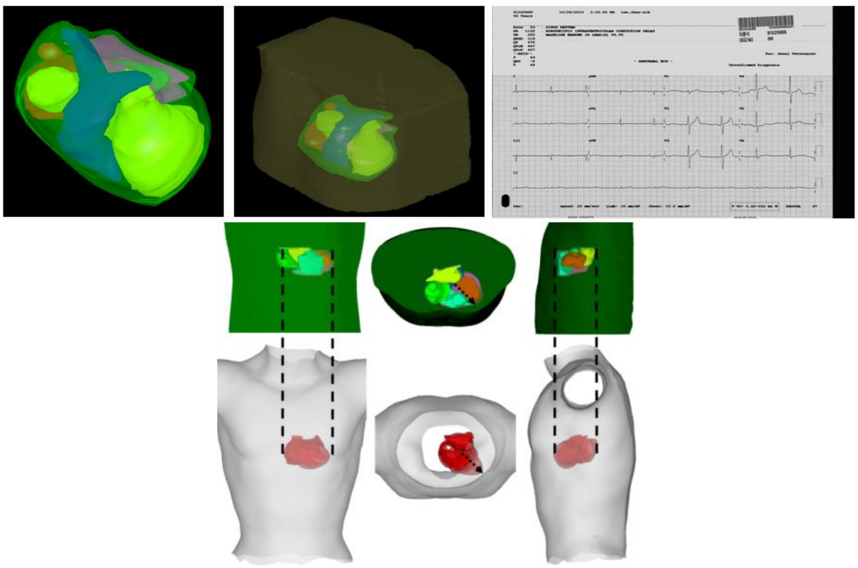
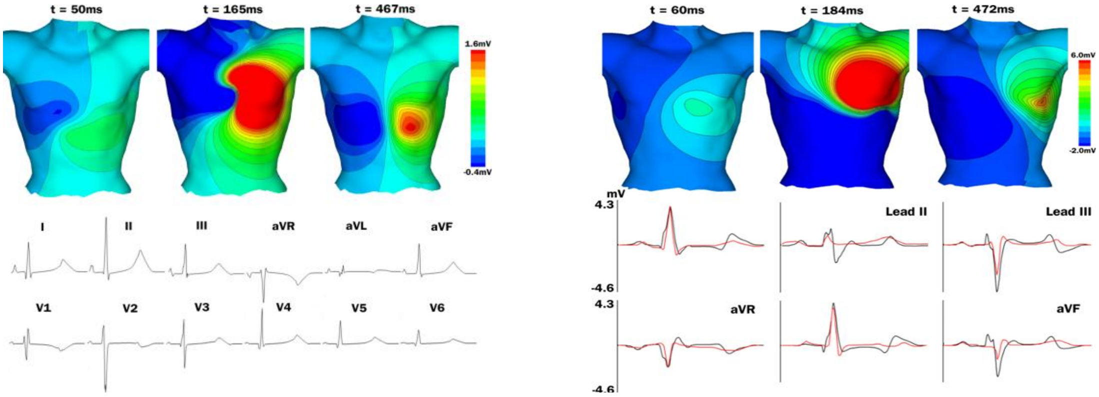


Figure 2 Heart model modification. 3D heart and torso reconstructed from a patient's CT image slices (top) (Seoul Veterans Hospital) and the standard FE model of the heart and torso matched with the CT images (bottom). Arrows indicate the direction of the septum.



(a) (b)

Figure 3 (a) Isopotential maps of the torso and following 12 leads ECG waveforms of normal person. Simulated isopotential maps of the torso when the P (left, t = 50 ms), R (middle, t = 165 ms), and T (right, t = 467 ms) peaks are generated, and the following pseudo-ECG waveforms of the 12 standard leads under normal conditions. (b) Isopotential maps of the torso and following EKG waveforms with patient-specific model. Simulated isopotential maps of the torso when the P (left, t = 60 ms), R (middle, t = 184 ms), and T (right, t = 472 ms) peaks are generated, and pseudo-ECG waveforms (red color) compared with the measured ECG of a hypertrophic patient (black color). The pseudo-ECG waveforms are non-dimensionalzed with the R peak value of the measured lead I ECG.

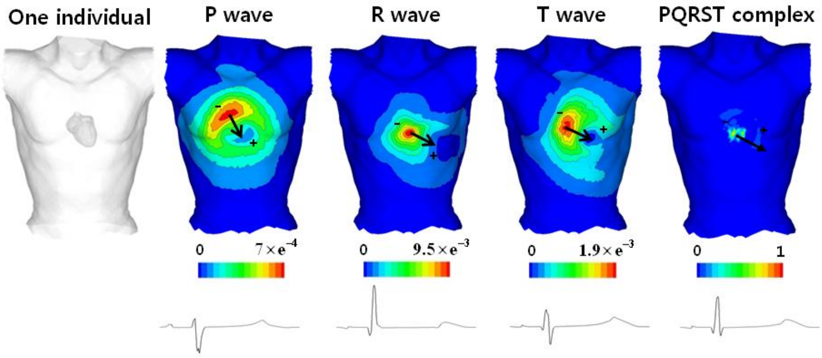


Figure 4 Optimal electrode placements and following ECG waveforms for an individual. Amplitude maps and optimal electrode placment of U-ECG for detecting P, R, T and PQRST complex peaks. Start and end points of the arrows indicate the optimal positioning of the two electrodes, NE and PE, respectively.

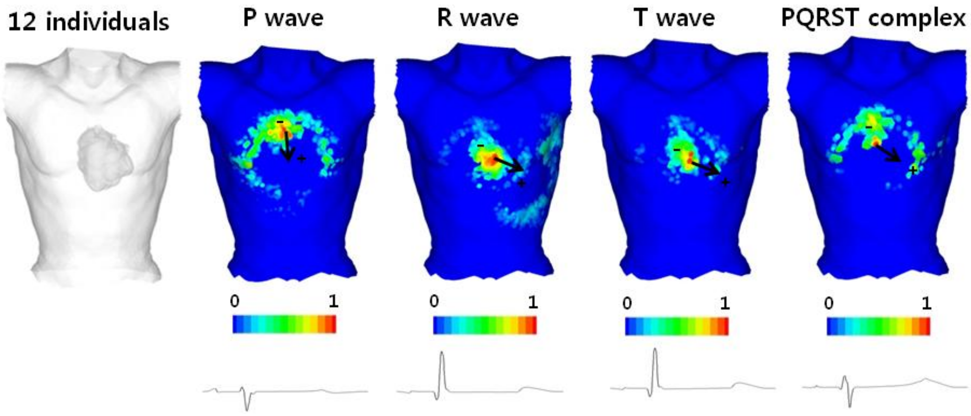


Figure 5 Optimal electrode placements and following EKG waveforms for 12 individuals. Amplitude maps and optimal electrode placment of U-EKG for detecting P, R, T and PQRST complex peaks. Start and end points of the arrows indicate the optimal positioning of the two electrodes, NE and PE, respectively.