# Localization of Site of Origin of Reentrant Arrhythmia from BSPMs by Means of a Heart-Model-Based Approach

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## Abstract

*We have developed a model-based imaging approach to inversely estimate the site of origin of reentrant arrhythmia from body surface potential maps (BSPM), with the aid of an ion-channel-level cardiac model. The reentry was successfully simulated and maintained in the cardiac model, and the simulated ECG waveforms over the body surface corresponding to a maintained reentry have evident characteristics of ventricular tachycardia. The present simulation results show that the present inverse imaging approach achieved an average localization error of about 1.5 mm when 5% Gaussian white noise was added to the BSPMs. This pilot simulation study suggests the feasibility of the model-based imaging approach in localizing the site of origin of reentrant arrhythmias from noninvasive BSPMs.*

## 1. Introduction

It is of significance and importance to noninvasively localize the site of origin of reentrant arrhythmia from body surface potential measurements. Currently, the traditional standard 12-lead ECG is applied for the noninvasive diagnosis of arrhythmia. However, the standard 12-lead ECG measurements lack of enough information on cardiac electrical events for reliably and accurately diagnosing arrhythmia or determining the location of origin of arrhythmia since ECG is acquired only from a few body surface sites far away from the heart. Body surface potential map (BSPM), which is noninvasively constructed by a large number of recording leads covering the body surface and contains more information than the standard 12-lead ECG [1], still suffers from the low resolution for localizing the origin of arrhythmia due to the smoothing effect of torso volume conductor. To compensate the torso volume conductor, a number of efforts has been made by solving the so-called ECG inverse problem, in particular the epicardial potentials and heart-surface activation imaging [2-10]. Recently, effort in the ECG inverse problem has been extended from the 2D heart surface to the 3D myocardial volume [11-21].

The present study aims to develop a model-based noninvasively imaging approach to inversely estimate the site of origin of reentrant arrhythmia from BSPMs, with the aid of an ion-channel-level cardiac model. Reentry was simulated in the ion-channel-level cardiac model and the corresponding ECG was computed on a spherical surface for constructing BSPMs. Computer simulations have been conducted to initially evaluate the feasibility of the proposed imaging approach in localizing the site of origin of reentrant arrhythmias from noninvasive BSPMs.

## 2. Methods

### 2.1. Forward modeling

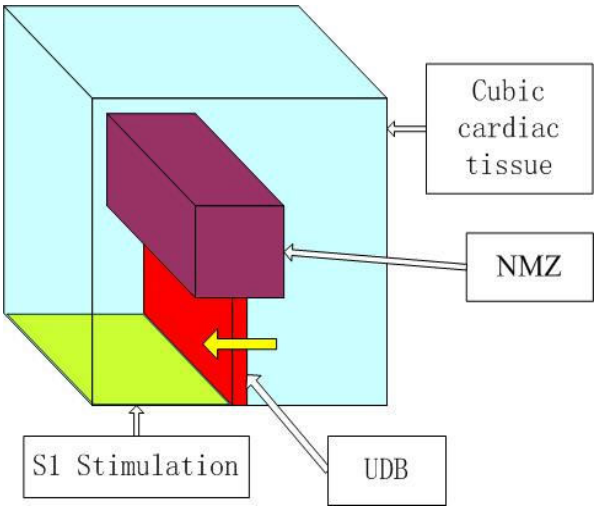


Figure 1. Schematic diagram of a reentry simulation setting.

In the present study, a cubic ion-channel-level cardiac model was constructed and used to simulate the reentry that is a geometrically complicated 3D phenomenon. The cardiac model contains 32×32×32 cellular units with a spatial resolution of 3 mm. For each cardiac cellular unit, its membrane kinetics of electrical activity, well known as

action potential (AP), was simulated by Beeler-Reuter (BR) model [22] and the rule based excitation propagation model [23] was chosen to simulate the propagation behavior of cardiac excitation in cardiac cells by a fixed excitation conduction mode and velocity.

To simulate reentry, two abnormal conduction areas were set in the cardiac model. One was a necrotic myocardial zone (NMZ) in where all cells were unexcitable, and another was a unidirectional block (UDB) cell wall on which the excitation current of each cell can propagate only in one direction. An excitation process in the cardiac model was initialized by the external stimulation current that was put on one cell or a group of cells. Figure 1 shows an example of schematic diagram of a reentry simulation setting in the cardiac model.

A spherical volume with a radius of 15 cm was used to simulate the heart-torso volume conductor. The ion-channel-level cardiac model was placed within the spherical volume conductor to approximately represent the heart-torso geometrical relationship. The eccentricity of heart in the torso was considered. The 200 sites uniformly distributed over the spherical surface were selected to represent the body surface electrodes.

## 2.2. Inverse approach

BSPMs at different time instant were constructed from the spherical surface ECGs, and the Gaussian white noise (GWN) was added to the BSPMs to simulate the "measured" BSPM. The central point of NMZ in the cardiac model is defined as the site of origin of a reentry in this simulation study. The site of origin of the reentry was estimated by minimizing dissimilarity between the "measured" and the simulated BSPMs. The nonlinear optimization problem was solved with the aid of the Simplex Method.

# 3. Results

## 3.1. Reentry and ECG simulation

In Figure 2, the third column shows a typical example of a series of the AP maps of a reentry at different time instants. It can be seen that a reentry, which was simulated by setting a NMZ area in the center of the ion-channel-level cardiac model, was successfully induced and formed in the cardiac model. The ECG waveform at a sphere-vertex electrode is shown in the right column of Figure 2. The BSPMs constructed from 200-lead ECGs at 6 representative instants over 2 hemispherical surfaces are shown in 2 left columns of Figure 2. From the right column of Figure 2, we can see that the waveforms of the simulated ECGs over the body surface corresponding to the maintained reentry has evident characteristics of ventricular tachycardia ECG, which is a possible result of reentry [24-26].

## 3.2. Localization of site of origin of reentry

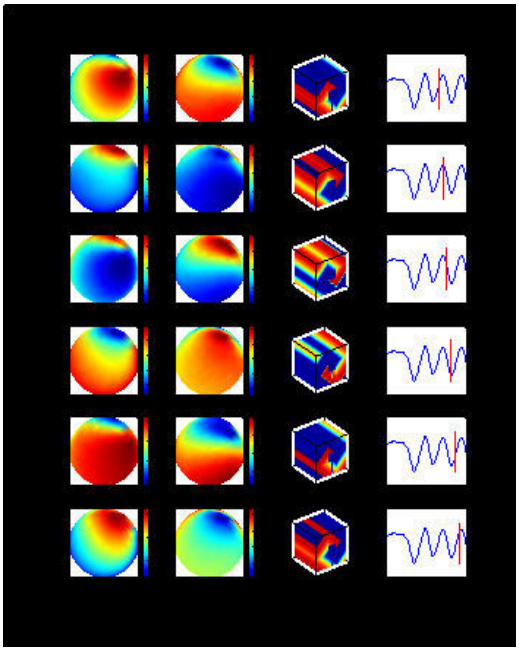

Figure 2. AP maps of a simulated reentry and the corresponding ECG and BSPM over a spherical surface. From left to right, the first 2 columns are the BSPMs at 6 instants over the superior and inferior hemispherical surfaces, respectively, the third column shows the AP maps in the cardiac model at 6 instants, and the right column shows the 1 sec ECG waveforms at a precordial electrode. The 6 instants are indicated by the red vertical lines shown in the ECG waveform of the right column.

Table 1. Summary of inverse solutions

| True site | Estimated site | Inverse solution | Spatial Distance (mm) |
|---|---|---|---|
| (16,16) | (21,21) | (17,16) | 3.0 |
| (16,24) | (11,21) | (15,24) | 3.0 |
| (16,9) | (21,11) | (16,9) | 0 |
| (9,16) | (11,21) | (9,16) | 0 |
| (24,16) | (21,21) | (24,16) | 0 |
| (8,8) | (11,11) | (8,8) | 0 |
| (8,24) | (11,21) | (8,24) | 0 |
| (24,24) | (21,21) | (22,24) | 6 |
| (24,8) | (21,11) | (24,8) | 0 |
| (16,26) | (11,21) | (15,25) | 4.2 |
| (16,7) | (21,11) | (16,7) | 0 |
| $E_{cc}$ (Mean ± SD): 0.9851±0.0039 | | | Mean: 1.5 |

Note: The site of a cubic NMZ could be specified by 2-integer coordinates due to the NMZ with a length as long as the side of the cardiac model cube shown in Figure 1.

Eleven sites in the cardiac model were randomly selected as the "true" sites of origin of reentry to test the performance of the proposed approach in localizing the site of origin of reentry. The sites of origin of reentry inversely estimated by the proposed approach and the spatial distance between the true site and estimated site of reentry are summarized in Table 1. These simulation results show the feasibility of the model-based imaging approach in localizing the site of origin of reentrant arrhythmia from BSPMs.

## 4. Discussion and conclusions

We have conducted a pilot simulation study to test the hypothesis that an ion-channel-level cardiac model based imaging approach may be able to localize the site of origin of cardiac reentrant arrhythmia.

Reentry may be induced by many abnormal physiological and pathological states of the heart [27]. A common reentry that is formed by the abnormal conduction area in myocardium was simulated by using the BR AP model. In the ion-channel-level cardiac model, the reentry was successfully formed and maintained, and the simulated ECG waveforms over a spherical surface represented the evident characteristics of ventricular tachycardia ECG.

To test the performance of the present imaging approach to localize the site of origin of reentrant arrhythmia, 11 sites in the cardiac model were randomly selected. The present inverse imaging approach achieved an average localization error of about 1.5 mm when 5% GWN was added to the BSPMs. While more realistic heart and torso models should be used in future investigations, the present promising results in this pilot simulation study suggests a possible way of localizing the site of origin of reentrant arrhythmia from noninvasive BSPMs and that this approach merits further investigations.

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