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Cardiac Source Localization by Means of a Single Moving Dipole Solution during Endocardial Pacing in an Animal Model

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***Abstract*—The accuracy of localizing the initiation site of cardiac activation by noninvasively estimating a single moving dipole (SMD) was investigated in a swine model. Body surface potential mapping (BSPM) and intracavitary noncontact mapping (NCM) were performed simultaneously during acute left ventricular (LV) endocardial pacing. For each animal, the boundary element model was constructed from preoperative magnetic resonance images (MRI). In each pacing study, the initiation site was localized by inversely estimating the location of an SMD from BSPM data. The results were compared with the precise pacing sites recorded by the NCM system. In total, four pacing sites from two pigs were analyzed, and the averaged source localization error was 16.8 ± 2.3 mm. The present results indicate the potential of localizing focal cardiac events by estimating single moving dipole.**

I. Introduction

TECHNICAL developments in recent decades have created various methods [1,5,7-12] in cardiac electrophysiological imaging by solving the so-called 'inverse problem' from the non-invasive body surface potential mapping (BSPM) data; and one of them is the single moving dipole (SMD) method [1-4,6,11]. It is related most often to determining the origin of focal cardiac arrhythmias with well-localized source [1-3] and also would potentially be useful in guiding catheter ablation [11,13]. However, so far the clinical breakthrough of this SMD technique has not been made, which mainly depends on the accuracy of the solution of the inverse problem [6,11,13]. It is thus of interest to quantify the localization accuracy of this method.

In the present study, we report preliminary results from an animal study to evaluate the performance of localizing the site of origin of focal cardiac activation by using the SMD technique. A pacing protocol is used and four of left ventricular (LV) endocardial sites from two pigs were paced to simulate focal ectopic beats. The accuracy of the SMD localization is accessed using the mean and standard deviation (SD) of the distance between the precise (obtained in intracavitary noncontact mapping) and the estimated pacing site (obtained from the inverse solution) for each of the four sites.

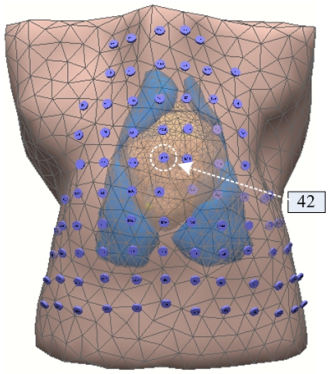

Fig. 1. Anterior view of the reconstructed boundary element model of the torso.

II. Materials and Methods

Experiments were carried out on two control pigs according to a protocol approved by the IACUC of the University of the Minnesota. The animals were anesthetized with a fentanyl infused at 0.75 mcg/kg/min; both of them were intubated and mechanically ventilated with 65% air and 35% O_2 to maintain a $PaCO_2$ of 40 ± 2 mmHg. For each animal, the preoperative magnetic resonance imaging (MRI; ECG gated to end diastole) was acquired before the *in vivo* mapping experiment. Acute endocardial surface pacing from either the LV anterior (LVAn) or LV posterior (LVP) was performed. During each of the above pacing study, BSPM with 90 disposable electrodes placed on the anterolateral chest (as shown in Figure 1) and intracavitary noncontact mapping (NCM; Ensite® 3000, St. Jude Medical Inc., St Paul, MN, USA) were performed simultaneously. The three dimensional (3D) locations of these pacing sites were recorded on the reconstructed LV geometry acquired with the NCM system.

After the completion of data collection, all source reconstructions using the SMD method were performed using the CURRY (Compumedica, El Paso, TX, USA) software package where the forward model was calculated by using the boundary element method (BEM). The boundary element model was constructed for each of the pigs from the preoperative MRI data sets, as shown in Figure 1. Homogeneous conductivity of 0.2, 0.04, and 0.6 S/m for the torso, the lungs, and the heart was assumed, respectively [14].

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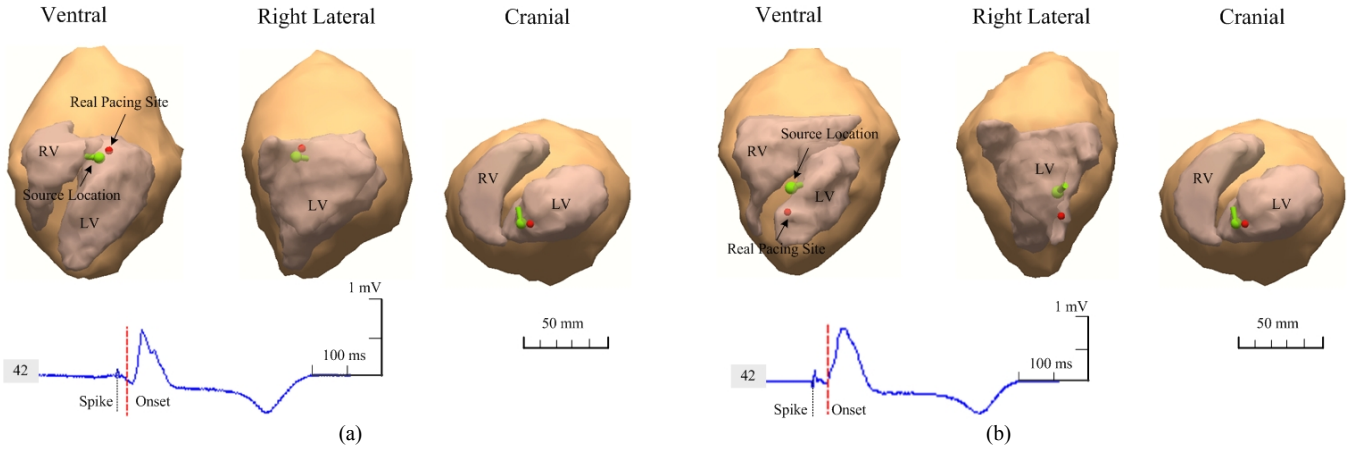

Fig. 2. Comparison of the actual pacing site and the estimated source location estimated from the single moving dipole solution during the endocardial LV pacing: **(a)** the LVAn site of the No. 2 pig and **(b)** the LVP site of the No. 1 pig. In each panel, top row: the real pacing site and the estimated source location viewed from ventral, right lateral, and cranial side, respectively; bottom row: one of the recorded BSPM signal (the corresponding surface electrode is marked out in the figure 1 (b)) during one ectopic cardiac beat produced by an endocardial LV pacing, where 'Spike' means the pacing stimulus instant, 'Onset' means the initial instant of evoked ventricular activation.

TABLE 1
SOURCE LOCALIZATION ERRORS DURING ENDOCARDIAL LV PACING

Pig No. and Pacing Site	Localization Error (mm)						Mean ± SD (mm)
	1	2	3	4	5	6	
1, LVAn	15.2	14.6	11.1	14.5	11.7	11.2	13.1 ± 1.9
1, LVP	25.6	24.0	25.1	26.6	23.7	26.5	25.2 ± 1.2
2, LVAn	8.5	13.8	12.0	12.3	6.8	9.9	10.6 ± 2.6
2, LVP	14.2	13.9	20.4	20.4	19.7	19.9	18.1 ± 3.4

For each pacing site, the 3D noninvasive localization of cardiac source was estimated by using a nonlinear optimization method [15] with the recorded BSPM data. In addition, the origin of the induced ectopic activity was located at the beginning of the myocardial evoked activation, herein defined as the onset instant.

The localization error was defined as the spatial distance between the computed dipole locations at the beginning of activation and the corresponding precise pacing site on the endocardial surface recorded by the NCM system.

III. RESULTS

In these *in vivo* studies, stable endocardial pacing within LV was successfully obtained in two control pigs and the SMD localization analyses were subsequently conducted.

Figure 2(a) shows a typical example of the source localization results that were estimated during pacing in the No.1 pig from the LVAn endocardial site, where the real pacing site (red dot) and the corresponding estimated dipole (green vector) are both presented in the reconstructed heart geometry. Figures 2(b) shows an example when pacing the LVP site of the No.2 pig. In addition, the pacing spike instant and the onset instant of the evoked activation are indicated in one of the recorded BSPM signal waveform (No. 42 channel, the corresponding electrode of this channel is marked in Figure 1), as shown in Figure 2.

In total, four endocardial sites in LV were paced, and 24 paced beats were analyzed (6 for each site). The estimation results are summarized in Table 1. Over the 24 beats analyzed, the averaged source localization error was 16.8 ± 2.3 mm.

IV. DISCUSSION

The present study represents an attempt to experimentally evaluate the performance of single moving dipole inverse solution in localizing focal cardiac activity in a well controlled setting. We chose the swine model due to its close approximation to humans in cardiac sizes, heart-torso geometries, and electrophysiological characteristics. While in experiments, the 3D locations of these pacing sites are precisely recorded by a clinical NCM system and subsequently used as a reference to quantitatively evaluate the localization accuracy of the SMD. Comparing with previous studies, such experimental results shall be useful in rigorously determining the performance and suitability of SMD in localizing focal cardiac activity, and provide insights into the clinical applicability of the SMD technique.

The present SMD solutions demonstrate that the localization results of pacing sites are in good agreement with the actual pacing positions recorded by the NCM system. The present accuracy of the SMD localization suggests that the SMD can localize the initial site of the ectopic cardiac activation with reasonable precision when the bioelectrical activity of the heart is well localized. The

SMD technique could be potentially useful for non-invasively indentifying focal arrhythmic sources [2, 4], (such as the pre-excitation sites in the Wolff-Parkinson-White syndrome and non-reentry ventricular tachycardia focus, etc) or conducting pre-interventional planning [11, 13]. Further investigations should be conducted in a larger number of animals and compared with other ECG inverse solutions.

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