Noninvasive Localization of Ectopic Activation Using BSPM and CT-Based Torso Model

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Abstract. *In this study accuracy of the inverse localization of ectopic ventricular activity in dependence on the used heart and torso model was examined. Best agreement between the positions obtained from the inverse solution and from the electrophysiological study was achieved when the CT-based torso and heart model was used. The use of a personally adjusted general torso model with the heart model obtained from CT gave less accurate but still acceptable location of the ectopic activity. If simplified geometric heart model was used, the results depended on the fidelity of its shape and position estimation and varied from acceptable locations to locations scattered within wide range of the ventricular volume.*

Keywords: body surface potential mapping; inverse problem of electrocardiology; torso model; ectopic activation.

1. Introduction

It has been shown elsewhere [1, 2] that cardiac imaging based on multichannel surface ECG and proper torso and heart model may be useful for non-invasive assessment of electrophysiological state of the heart by solving the inverse problem of electrocardiology. The accuracy of the solution may depend on the selected model of the cardiac sources, method used for assessment of its parameters, and fidelity of the ECG data and torso model. In this study the accuracy of inverse localization of ventricular ectopic activity in dependence on the used heart and torso model was examined.

2. Subject and Methods

Two male patients (P1: 57 years old man, P2: 17 years old man) with premature ectopic activity in the ventricles causing ventricular tachycardia underwent 10 minutes of body surface potential mapping (BSPM) using the ProCardio 8 system with 62 electrodes placed according the Amsterdam lead system. Computed tomography (CT) scanning with slice thickness of 0.3 mm and a pixel size of 0.885 mm was performed on patients with attached ECG electrodes using the Toshiba Aquilion ONE™ system. Finally, intracardiac electrophysiological study (EPS) was performed using the Bard LabSystem™ PRO EP Recording System. To reveal the position of the premature ectopic activity, St. Jude EnSite NavX™ cardiac mapping and navigation system was used in the first patient and standard protocol under X-ray was used for the second patient.

For non-invasive estimation of the site of the premature ectopic activity an inverse solution based on dipole model of the cardiac electric generator and measured BSPM data was used.

Integral map over the initial time interval of the ectopic activity was used as the input for its inverse localization. The integral map values in body surface points are defined as

$$im = \int_I bm(t) = \mathbf{A} \int_I g(t) = \mathbf{A}s \qquad (1)$$

where **A** is a time independent transfer matrix that represents the properties of the inhomogeneous torso as a volume conductor (i.e. relations between potentials in individual surface points and multiple elementary dipoles within the myocardium), *g(t)* is the multiple dipole generator in particular time instant t of the heart activation and s represents an integral generator characterizing the searched pathological electrical activity within the examined time interval of the ectopic activity.

The equivalent integral generator EIG representing the original integral multiple dipole generator *s* in equation (1) can be then computed as:

$$EIG = \mathbf{A}^{+} im \qquad (2)$$

where **A+** is the pseudo-inverse of the transfer matrix **A**.

The inverse solution is an ill-posed problem that in case of local pathology (where the EIG represents only small volume of the myocardium) can be solved by approximating it by a single dipole. In the method used in this study [3, 4] the EIG is defined only by three parameters – components of the dipole moment. To avoid solving a nonlinear problem, the other three dipole parameters – its coordinates are determined so that the dipole moments are computed for many predefined possible positions within the ventricular volume that are several millimeters apart (their spacing determines the resolution of the method). The position of the pathology is then determined as the location in which the EIG best represents the input data *im* and is defined by the criterion that the root mean squared difference between the map generated by the EIG and the input integral map im is minimal. Several torso models of different fidelity were tested for the inverse solution (Fig. 1):

A - model with a common shape of torso with lungs adjusted to patient chest dimensions [5] and simplified geometrical heart model adjusted to the real heart size and position (the long heart axis was properly scaled and positioned, the short axis was properly rotated);
B - the same torso and lungs model as in A, with heart model shape and position taken from the CT scan;
C - realistic model of the torso, lungs and heart taken from the CT scan.

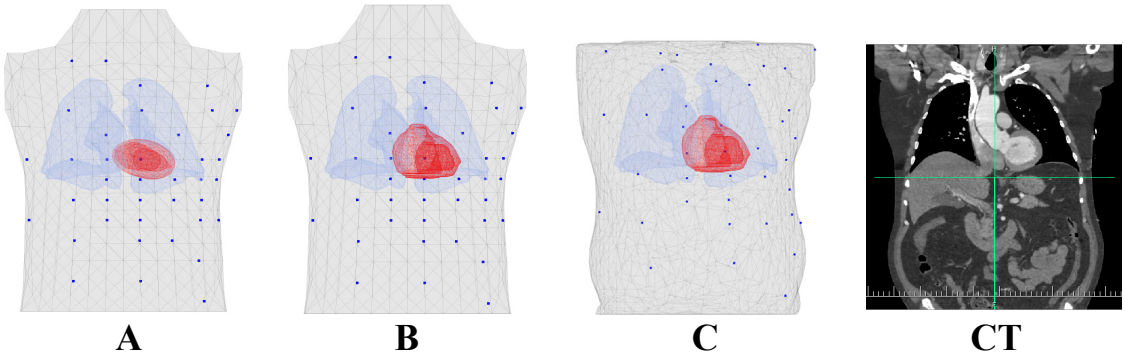

Figure 1: Torso models and CT scan of patient P1. Three models of torso, lungs and heart described in the text were used in the inverse computations. Dots mark positions of anterior electrodes.

3. Results

In patient P1, the intracardiac EPS identified the initial ectopic activation in the left ventricle in the posterior septum near heart base (Fig. 2, left), in patient P2 the focus was found in the anterior free wall of the left ventricle, near the aortic sinus (Fig. 2, right).

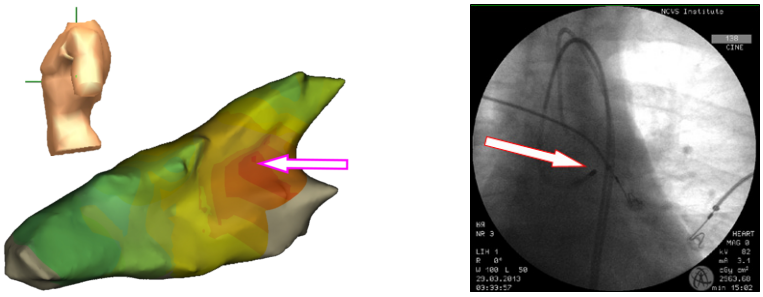

Fig. 2. Initial ectopic activation sites obtained from the EPS: from the navigation system during intracardiac mapping in patient P1 (left) and from the X-ray image as the position of the ablation electrode tip in patient P2 (right).

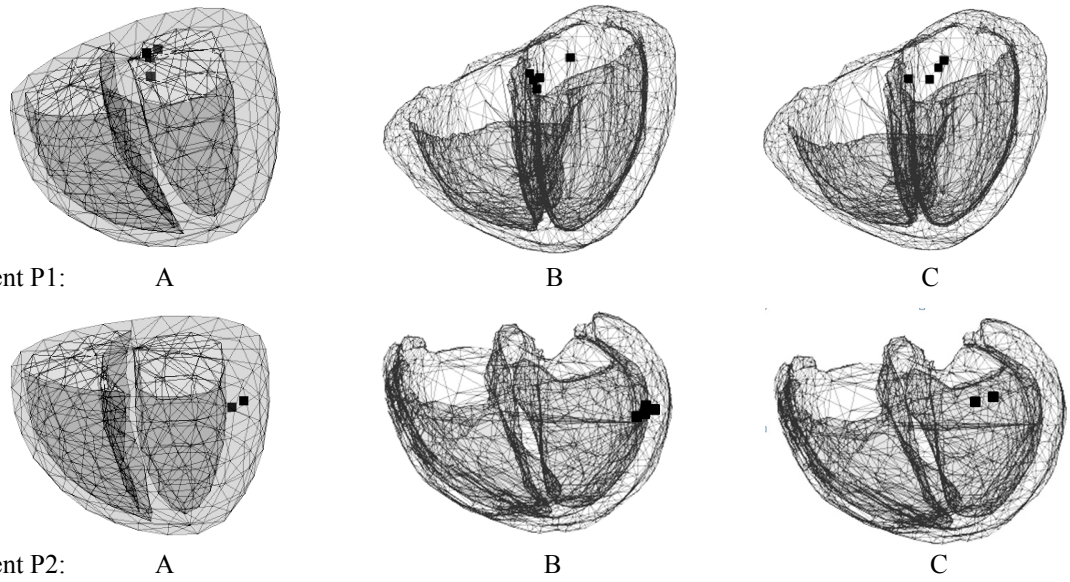

Fig. 3. Inversely found sites of initial ectopic activation (marked by little squares) in patients P1 and P2 when three different torso-heart models A, B, C described in the text were used. Five ectopic beats were used in both patients; in some cases the same site was obtained from different ectopic beats.

When torso models B or C were used, the sites of initial ectopic activity in patient P1 were located in the posterior septum near the heart base with dipole direction suggesting activation from the right to the left ventricle. The location slightly varied depending on the evaluated ectopic heart beat and was within few millimeters from that found by the EPS. When torso model C was used, the solution was more accurate and stable within the evaluated ectopic beats.

In patient P2 the ectopic beat focus was located near the aortic sinus. With torso models B and C the inversely estimated sites were positioned similarly in the anterior free wall of the left ventricle near the heart base. The dipole orientation suggested epi-to-endocardial and base-to-apex initial activation that was more pronounced when model C was used.

If the simplified torso and heart model A was used and the heart model was adjusted to approximately correspond to the real heart, in both patients the noninvasively located sites of the ectopic activity were also in concordance with the EPS as shown in Fig. 3 left.

4. Discussion

The study enabled only partial verification of the noninvasively obtained ectopic foci. In patient P1, merging of ventricle shapes obtained from CT and from the navigation system was not perfect because some differences reached more than 10 mm. Moreover, due to arteria femoralis sinistra occlusion, the EPS was terminated without ablation that could confirm the

localized focus. In patient P2 the location of the focus from the EPS study was only approximate; it was obtained from X-ray image as the location near the tip of the ablating electrode but the heart shape was not clear enough. Nevertheless, in both patients there was good correspondence between the foci estimated inversely and from the EPS if torso and heart models B or C were used.

If the simplified geometrical heart model in model A was used without any adjustment (if no information on the heart shape and position was available), the results in both patients varied in dependence on how close the heart model was to reality and the inversely estimated sites were scattered in wide range of the ventricular area, sometimes several centimeters far from the site obtained from the EPS.

The results of the inverse localization slightly depended also on the evaluated time interval. Several intervals within first 30 ms of the ectopic activity, from 10 to 30 ms long were attempted. Despite the longer and later intervals in most cases yielded more stable results, the obtained locations were sometimes shifted from the expected positions, probably due to the larger activated area that corresponded to those evaluated intervals.

5. Conclusions

Fidelity of the torso and heart model can strongly influence the inverse localization of the ectopic activity. Best results in both patients were achieved with a torso model based on the whole torso CT scan. An approximate torso shape model adjusted to patient chest dimensions with properly positioned heart model based on a CT-scan of the heart area gave less accurate but still acceptable location of the ectopic activity. However, when the real heart geometry relations were maintained in the simplified heart and torso model, the results were still able to give preliminary information about the position of the initial ectopic activity.

Acknowledgements

This study was supported by research grants 2/0131/13 from the VEGA Grant Agency and APVV-0513-10 from the Slovak Research and Development Agency in Slovakia, by project Biomedicine University Research Park Bratislava (ITMS code 26240220087) and grant 3/229/OHK4/3T/17 from the SGS CVUT in Czech Republic. The authors thank the medical team from the Institute of Cardiovascular Surgery of the Academy of Medical Sciences of Ukraine in Kyiv for cooperation in clinical measurements and kind permission to use the data.

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