Influence of Modeled Heart Cavities on the Noninvasive Localization of Ectopic Ventricular Activity

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Abstract. *Noninvasive localization of premature ectopic ventricular activity was performed for four patients using integral body surface potential maps and inverse solution to one dipole. The influence of two different models of heart cavities on the accuracy of the inverse solution was studied. Despite improvement in some cases, better accuracy of the inverse solution for more detailed models of heart cavities was generally not achieved.*

Keywords: Body Surface Potential Mapping, Ectopic Ventricular Activation, Inhomogeneous Torso Model, Inverse Problem of Electrocardiography

1. Introduction

It is a common knowledge that premature ventricular contractions (PVC), or ventricular ectopic beats, in patients with local myocardial ischemia or infarction might cause ventricular fibrillation and even lead to death. It is possible to treat PVC with anti-arrhythmic drugs or by a catheter radiofrequency ablation. The ablation is an invasive procedure, performed during the electrophysiological study (EPS) in a catheter laboratory. The catheter is guided under X-ray control and/or by a 3D navigational system to localize the focus of the pathological PVC. The duration of such a procedure usually takes up to several hours. Therefore, it would be desirable to localize the PVC origin before the invasive EPS and significantly decrease the time of the ablation procedure. The identification of local changes in ventricles from body surface potential maps (BSPMs) was proposed in [1]. Body surface potential mapping is a noninvasive method and in comparison to invasive EPS it does not present additional risks as bleeding, infection, damage of the vessel, perforation of the heart, etc. The localization of the PVC from BSPMs by an inverse solution might be influenced by various factors, such as the number of measured leads for BSPM computation, the type of the used BSPMs, the model of the patient's geometry or the method of the inverse solution.

In this study noninvasive localization of the PVC origin in four patients was performed using an inverse solution to one dipole [2] computed from integral BSPMs. The influence of the extent of patient-specific heart cavities included in the torso model on the inverse solution fidelity was studied.

2. Material and Methods

Two male (Pat002-57Y, Pat004-77Y) and two female patients (Pat005-43Y, Pat007-54Y) with premature ventricular activity underwent a measurement of BSPM, computer tomography (CT) scanning and intracardiac EPS using the Carto 3 navigation system. All procedures were approved by Ethic Committee of the University Hospital Kralovske

Vinohrady where the data were collected after obtaining written informed consent from patients.

Multichannel ECG recording was performed using ProCardio-8 system [3] with 1 kHz sampling frequency with 96 (12 stripes with 8) evenly distributed Ag/AgCl electrodes on patient's thorax (Fig. 1A). For each patient five ectopic beats were selected from the ECG record and processed to compute integral BSPMs for initial 0-15 ms interval of the ventricular activation [4] (Fig. 1C). After multichannel ECG recording, the patients underwent CT scanning of the whole torso (slice thickness 0.3 mm) with fixed ECG electrodes (Fig. 1B).

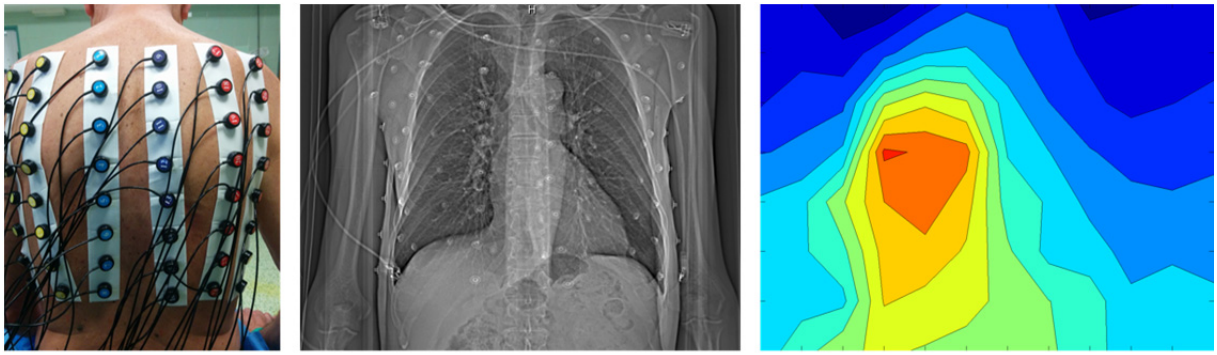

Fig. 1. Input data acquisition for inverse solution. A: Measurement of the multichannel ECG record using 96 electrodes. B: CT scan of torso with electrodes. C: Computed integral body surface potential map for the initial interval of premature ventricular activation.

From the obtained CT images patient-specific 3D geometries of torso, lungs, atria and ventricles (epi- and endocardial surfaces), aorta and pulmonary artery were created (Fig. 2) using TomoCon Workstation® software ver. 20.

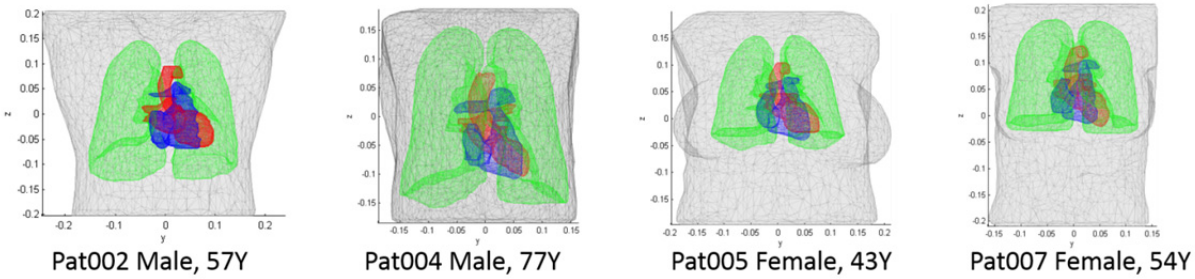

Fig. 2. CT-based 3D models of patient-specific geometries of the torso, lungs and heart cavities.

On the next day during intracardiac EPS the ablation of the PVC origin was performed in each patient. Location of the pathological arrhythmogenic tissue was defined using the electrophysiological navigation system. Results of the intracardiac intervention were compared with the results of the inverse solution computed from the measured BSPMs.

The inverse solution was based on dipole model of the cardiac electric generator computed from measured integral BSPMs representing the initial PVC activation. Integral BSPMs can be generally defined as

$$im = \int_I \phi(t)dt \qquad (1)$$

where im integral body surface potential map,
$\phi(t)$ body surface potential map in specific time instant,
I examined time interval of the initial activation.

Assuming that the area activated during the examined time interval can be represented by a single dipole, the inverse solution in predefined position in the ventricles can be computed using the equation:

$$G' = \mathbf{B}^{+} im \tag{2}$$

where G' dipolar equivalent integral generator,
$\mathbf{B}^{+}$ the pseudo-inverse of the transfer matrix B representing relation between the equivalent heart generator and potentials on the torso representing an inhomogeneous volume conductor.

Equivalent generator G' was computed for all positions of a regular 5 mm grid in the modeled ventricular myocardium. The best position of the equivalent integral generator was selected according to the criterion of the minimal value of relative residual error RRE between the input integral BSPM (im) and BSPM computed from the equivalent integral generator G' (Rm) obtained by the formula:

$$RRE = \sqrt{\sum_{i=1}^{n} (im_i - Rm_i)^2} \Big/ \sum_{i=1}^{n} im_i^2 \tag{3}$$

where n is the number of measured points in the BSPM.

Two torso models, reconstructed from the CT scan were studied: A - torso with lungs and ventricles; B - torso with lungs, atria, ventricles, aorta (AO) and pulmonary artery (PA). The conductivity of lungs was assumed four times lower than conductivity of the torso and conductivity of heart cavities, AO and PA was assumed three times higher than conductivity of the torso.

3. Results

Results of the intracardial EPS were compared with the inverse solution from 5 ectopic beats for both torso models in each patient. The number of "correct" resulting dipoles out of five possible results for both torso models in each patient is shown in Fig. 3. For Pat002 no correct inverse solution was obtained. In Fig. 4 all inverse solutions for Pat002 are localized in the anterior part of the left ventricle, while the successful ablation was performed in the posterior part of the left ventricle (see arrows in Fig. 4C). For three other patients the results were more promising, the best results were obtained for Pat005 where 4 inversely found dipoles corresponded with the position of the initial ectopic activity found during the EPS.

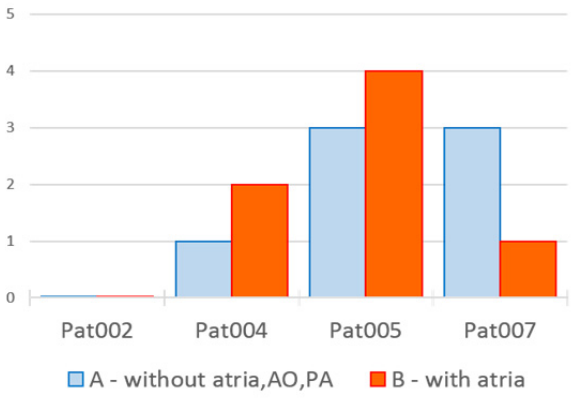

Fig. 3. Number of correct resulting dipoles for all 5 ectopic beats and for both types of the torso model (without and with atria, AO, PA).

4. Discussion and Conclusion

Preliminary results of the influence of the atria, aorta and pulmonary artery cavities models on inverse solution were obtained. For torso model A, the results in the female group were considerably better than in the male group. Comparison of the A and B models did not show whether the presence of atria, aorta and pulmonary artery in the models of cavities filled with blood can increase the accuracy of the inverse solution.

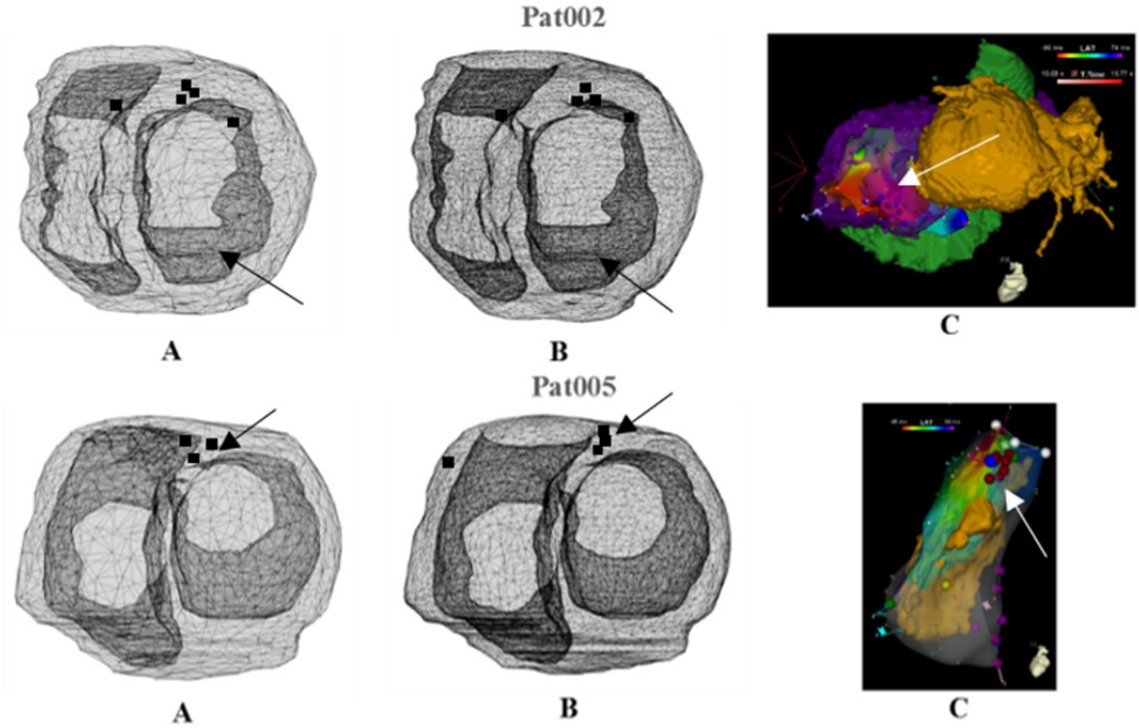

Fig. 4. Results of the inverse solution and ablation positions from the electrophysiological studies for Pat002 (the worst) and Pat005 (the best). A: heart model with only ventricular cavities; B: heart model with ventricular and atrial cavities, AO and PA (apex to base view); C: intracardial model from the Carto 3 navigation system with CT.

Obtained "incorrect" results can be caused by improper selection of the time instants for integral BSPMs, inaccuracy in the models from CT scans, improper signal processing, simplifications in the thorax model (conductivities of lungs and blood in heart cavities), grid size of the mesh for predefined dipole positions, etc. All above mentioned factors should be studied in more details. However, despite the noninvasive localization was not accurate enough in all patients, the presented method could be helpful for shortening the time needed for successful ablation procedure.

Acknowledgements

The present study was supported by research grants 3/229/OHK4/3T/17 from the SGS CVUT in the Czech Republic, APVV-0513-10 from the Research and Development Agency and 2/0131/13 from the VEGA Grant Agency in Slovakia and by the project Biomedicine University Research Park Bratislava, Slovakia (ITMS code 26240220087).

References

[1] Tysler M, Kneppo P, Turzova M, Svehlikova J, Karas S, Heblakova E et al. Noninvasive Assessment of Local Myocardium Repolarization Changes Using High Resolution Surface ECG Mapping. *Physiological Research*, 56(1): S133–S141, 2007.

[2] Tysler M., Tinova M. Representation of Myocardium Depolarization by Simple Models. In proceedings of the Computers in cardiology, 1993, 703-706.

[3] Rosík V, Karas S, Hebláková E, Tyšler M, Filipová S. Portable Device for High Resolution ECG Mapping. *Measurement Science Review,* 7(6): 57-61, 2007.

[4] Punshchykova O, Svehlikova J, Kneppo P, Maksymenko V, Tysler M. Noninvasive Localization of the Ectopic Focus Using Time Integral ECG Mapping. *Experimental and Clinical Cardiology*, 20(7): 1564-1570, 2014.