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# Noninvasive finding of local repolarization changes in the heart using dipole models and simplified torso geometry☆

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**Abstract** Two inverse methods using dipole models for noninvasive assessment of local repolarization changes were investigated and compared in the simulation study. Lesions with changed repolarization were modeled by shortening of the action potential durations in ventricular regions typically influenced by occlusion of coronary arteries. Corresponding body surface potentials were computed using a multiple dipole model of the cardiac generator and an inhomogeneous torso model. Position of each lesion was then estimated by an inverse solution to a single dipole and to a group of five neighbouring dipoles. For both methods the lesion localization error was evaluated and its dependence on the lesion size and the noise in input data was studied. When no noise was present in the input data, the use of the inverse method to a group of dipoles instead of a single dipole resulted in an unsubstantial reduction of the mean localization error of small lesions from 0.6 to 0.5 cm. For medium and especially for large lesions the mean localization errors decreased significantly from 1.1 to 0.6 cm and from 2.3 to 1.0 cm, respectively. The inverse solution to a group of five dipoles was more sensitive to noise. However, for large lesions it still gave better results than the solution to a single dipole if the signal to noise ratio was higher than 30 dB.


*Keywords:* Ischemic lesion; Body surface potentials; Dipole model; Inverse solution

## Introduction

Local narrowing or occlusion of a coronary artery causes a lack of oxygen in the supplied myocardium and development of an area with changed repolarization phase of the action potential (AP) of the affected myocytes. Changes of the AP repolarization phase are reflected in a shift of the ST segment and changed T wave in measured ECG signals[1,2] or in corresponding changes in body surface potential maps (BSPMs).

BSPMs are computed from ECG signals measured by multiple leads on the patient's thorax in order to obtain a comprehensive knowledge about the heart condition. It has been shown that such measurements give more information about the cardiac electrical generator than traditionally used standard 12-leads ECG.[3] Besides the diagnostic evaluation of the BSPM pattern itself,[4,5] various inverse methods based on the BSPMs and mathematical modeling of the cardiac electric field have been developed[6,7] to identify the processes directly in the heart volume or on its surface. The variety of the proposed inverse methods results mainly from the assumed type of the equivalent cardiac generator that should be recovered by the inverse computation.

Considering the spatially distributed equivalent cardiac generators, their most frequently used description obtained by the inverse solutions is in the form of epicardial potentials,[8] distribution of transmembrane potential[9] or the uniform double layer.[10] Another approach of imaging the local activation and recovery timing was introduced in the study of van Dam et al.[11]

In spite of its simplicity, the equivalent dipolar source can be used in the inverse solution computations for some cases, when the searched pathological changes in the heart are localized in a relatively small area. The single dipole as an equivalent cardiac source was suggested e.g. for finding the preexcitation site (accessory pathway) in Wolf-Parkinson-White syndrome.[12,13] Another possibility to use the single equivalent dipole is the inverse localization of small regions with changed repolarization (ischemic lesions), which occur during ischemia caused by local narrowing or occlusion of a

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coronary artery. The changes in ECG signals during the STT interval are well noticeable in integral BSPMs as it was shown in the study of Trudel et al.[14]

The inverse localization of small ischemic lesions by an inverse solution to a single dipole using a difference STT integral map (DIM) was suggested in the study of Tysler et al.[15] The location of the ischemic lesion was represented by the location of a single inversely estimated dipole computed from the DIM. In a simulation study, lesion localization errors of about 1 cm were obtained for small and medium subendocardial or subepicardial lesions but significantly larger errors from 2 to 4 cm were obtained for large and transmural lesions.

A modified inverse method was suggested in the study of Svehlikova et al[16] in order to reduce the localization errors in cases of large and transmural lesions. The effect of the ischemic lesion was represented by a group of neighbouring dipoles. Various numbers of the group members (from 2 to 6) were tried for inverse solution. The best results were achieved when the group consisted of 5 dipoles.

In the present study we investigated the robustness of the inverse method using a single dipole and the method using a group of five dipoles by adding a Gaussian noise to the input data. Localization errors for various lesion sizes and various levels of additive random noise in the input DIM were evaluated and compared.

## Material and methods

### *Forward simulation*

The simplified model of the heart ventricles defined by ellipsoids consisting of 1 $mm^3$ elements described in the studies of Szathmary and Osvald[17] and Lenkova et al[18] was used. Realistically shaped time course of AP was assigned to each element and corresponding AP value was used in each time step of the simulated activation. The spread of activation was simulated according the Huygens principle of wave propagation and computed using a cellular automaton approach. In each time step of the activation, the elementary dipole moments were computed from the difference of APs of adjacent elements of the heart model, thus the equivalent cardiac generator was presented by a multiple-dipole model. The heart model was inserted into a realistically shaped inhomogeneous torso derived from the Dalhousie torso model[19] and corresponding BSPMs were computed using the boundary element method (BEM). The inhomogeneous torso model and the simplified model of myocardial ventricles used in the simulations are shown in Fig. 1.

Sixty six lesions with changed repolarization were modeled as a part of a sphere or a part of an ellipsoid at the endocardial or epicardial surface of the modeled ventricular myocardium in areas typical for stenosis of one of the three main coronary vessels: anterior – in the region supplied by the LAD, posterior – in the region supplied by the LCx and inferior – in the region supplied by the RCA.

The lesion size was specified as the percentage of the number of elements with changed repolarization to the number of all elements forming the ventricular myocardial mass. The modeled lesions were divided according to the size of the affected ventricular volume to three groups: small (0.5–1% of the volume), medium (2.5–6%) and large (8–14%). The mean radius of small lesions was 1.4 cm, of medium lesions 2.4 cm and of large lesions 3.3 cm. The repolarization changes in the lesions were modeled by shortening the AP duration by 20%. When the elements with the changed repolarization were modeled in the whole thickness of the ventricular wall the lesion was considered transmural.

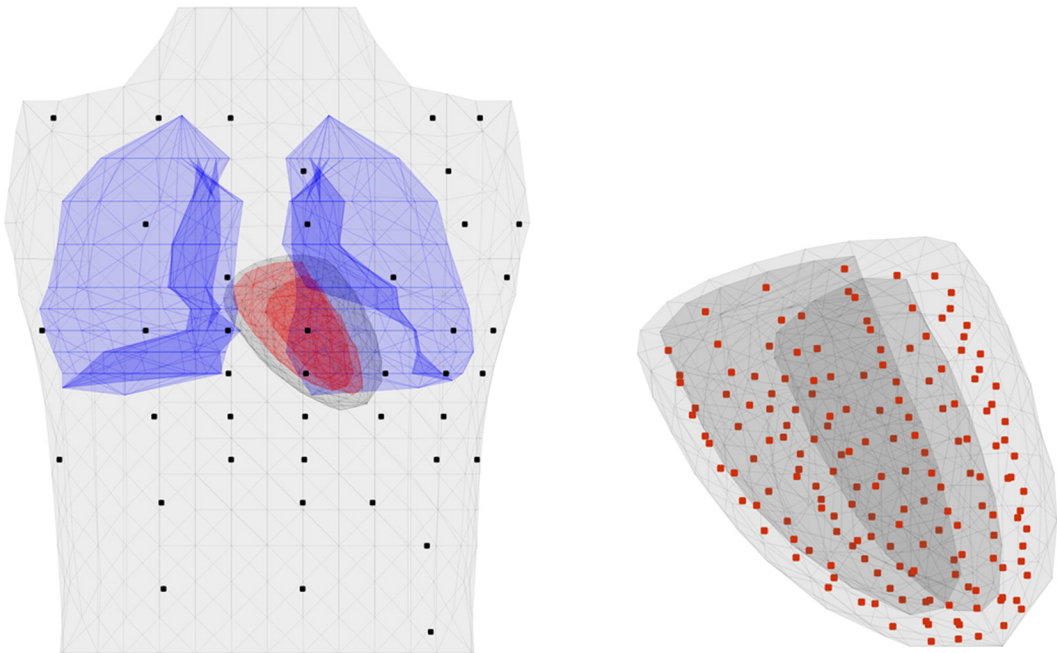

Fig. 1. Left: Inhomogeneous torso model used in the study. Black dots indicate the 41 anterior positions of the 64 measuring leads in which the DIM was computed. Right: Simplified ventricular model with 168 predefined possible positions of dipoles representing the modeled lesions in the inverse solutions.