# Inverse Identification and Localization of Two Ischemic Lesions in Homogeneous or Inhomogeneous Torso Model

Švehlíková J, Mačugová J, Turzová M, Tyšler M
Institute of Measurement Science, Slovak Academy of Sciences, Bratislava, Slovakia
umersveh@savba.sk

*Abstract. In presented study two types of realistically shaped torso models were used in inverse solution for localization of two ischemic lesions. In the inhomogeneous torso model the lungs and heart ventricles' cavities filled with blood with different conductivities were included. In the homogeneous model only the average conductivity of the whole torso volume was considered. Six sizes of ischemic lesions were modelled in typical positions in left ventricle. For each size the set of 12 or 24 pairs of lesions was created. The possibility to identify the modelled lesions and the localization error were evaluated and compared for both torso models. All observed properties of the inverse solution were better if the internal inhomogeneities were taken into account, the localization error was lower by 0.5cm on average.*

## 1 Introduction

The coronary artery disease is one of the most common cardiologic diagnoses which yields to sudden and fatal decease. It is desirable to learn of such problems in advance rather than to have to solve the serious acute situation. Modelling of electrical activity of the heart could be one of the tools to improve the early diagnostics of this specific heart disease.

Pathological changes in the heart, e.g. repolarization changes due to ischemia, can be characterized by differences between body surface potentials obtained under normal conditions and under conditions with manifestation of the pathology [1]. Such differences can be described and visualized by a difference integral map (DIM).

In real situations when the measurements are performed on patients we can get the DIM during the so called stress test. It is a set of electrocardiographic measurements on a patient starting with measurements during the rest conditions and continuing with measurements during increasing physical or mental load. During the rest the electrocardiogram (ECG) is normal, during the stress the oxygen demand increases and in ischemic lesions it is not met because of narrowing and non-elasticity of ischemic vessels. This situation is reflected in ECG mainly by changes in ST segment and T wave [2].

If the pathological changes in the heart occur only in one or two small areas, the equivalent electrical generator producing the DIM can be represented by a single dipole or by a combination of two dipoles. A noninvasive method for identification of one or two simultaneous ischemic lesions from DIM [3] was suggested in a simulation study. For each simulated case a DIM was computed by subtracting the body surface integral map simulated for the healthy heart model from the map simulated for a heart model with two local ischemic lesions. The DIM was used for the solution of the inverse problem of electrocardiography with two dipoles and criteria for identification of cases with two ischemic lesions were proposed [4].

In general, human torso is a nonhomogeneous object with various conductivity properties. Solution of the forward problem of electrocardiography means computation of potentials on the surface of a torso generated by action potentials in the heart. For this purpose the torso is usually considered to be an inhomogeneous but piecewise homogeneous volume. The main inhomogeneities represent large body organs such as lungs and ventricular cavities situated near the heart muscle with their different and characteristic electrical conductivity. However,

in real measurements we usually do not have the knowledge about the precise position of the internal inhomogeneities. The aim of this study was to compare the results obtained in inhomogeneous torso model with the inverse solution assuming only homogeneous torso.

## 2 Methods

In the simulation study we used a simplified geometrical model of heart ventricles. The whole volume representing the myocardial muscle was divided into small cubic elements representing groups of myocardial cells. Depending on the relative position of the cells towards the epicardium and endocardium, an action potential of different length was assigned to each element. The shape of action potential was modeled according the experimental observations [5]. In corresponding parts of endocardium representing the conduction system in real heart the propagation velocity was simulated 3 times higher than in the rest of the myocardium. The activation of the myocardium was simulated by a cellular automaton and the multiple dipole equivalent electrical generator was created.

The cardiac electric field was computed in realistically shaped torso model using boundary element method.

Ischemic lesions with changed repolarization were simulated by shortening the myocytes' action potentials by 20% in three myocardium areas typical for stenosis of main coronary vessels – anterior – supplied by left anterior descending artery (LAD), inferior – supplied by right coronary artery (RCA) and posterior – supplied by left circumflex artery (LCx). In each area 6 sizes (denoted S_1, S_2, S_3, M_1, L_1 and XL_1) of subendocardial and subepicardial lesions shaped as ellipsoids or spherical caps were modeled. They differed in their height and radius (i.e. the portion of the whole volume of myocardium) as it is shown in Table 1. To model double lesions (two simultaneous lesions), combinations of two lesions of the same size in different myocardium areas were used (Fig.1).

| size | approx. height [cm] | % of volume | std of dist. [cm] | max. dist. [cm] |
|---|---|---|---|---|
| S_1 | 0,5 | 0,13 | 0,55 | 0,77 |
| S_2 | 0,5 | 0,53 | 0,94 | 1,45 |
| S_3 | 0,5 | 1,29 | 1,28 | 1,95 |
| M_1 | 1 | 0,91 | 0,92 | 1,35 |
| L_1 | 1,5 | 2,94 | 1,28 | 1,91 |
| XL_1 | 1,5 | 4,14 | 1,86 | 2,87 |

Tab 1. The properties of modeled ischemic lesions. The approximate height is measured from the endocardial or epicardial surface resp. In the 4$^{th}$ and 5$^{th}$ column, the standard deviation of distance or maximal distance of the points representing the lesion from the gravity centre of the lesion are displayed.

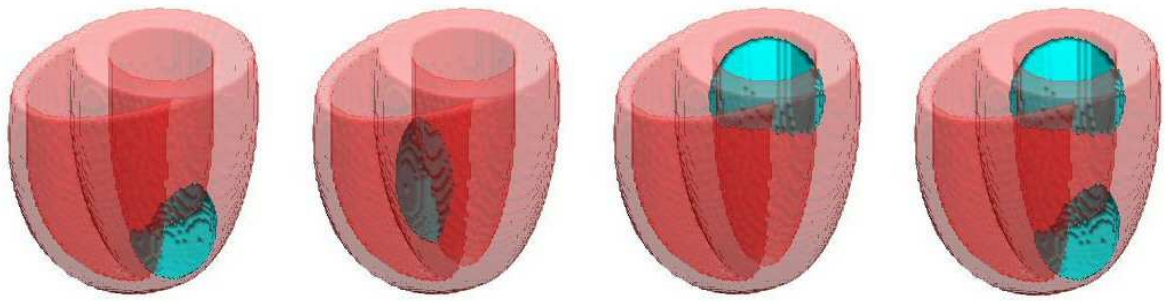

Fig 1. Positions of modeled lesions in simplified model of heart ventricles. From left to right: anterior, inferior and posterior position and the combination of two lesions.

First, surface potentials and QRST integral maps were computed for the normal activation and for simulated pathological cases. Then, corresponding DIMs were used to calculate the inverse solutions with two dipoles. The inverse solution was based on singular value decomposition (SVD) of the transfer matrix and was calculated for all possible dipole pairs with dipoles located in any two of the 168 predefined locations regularly spread within the modeled ventricular myocardium (14 028 pairs).

For each DIM, the best representative pair of equivalent dipoles was chosen using the criterion of the minimal rms difference (RMSDIF) between the original DIM and the map generated by the inversely estimated pair of dipoles. However, this criterion usually had no sharp minimum and for several dipole pairs their RMSDIF varied only very slightly from the minimum. Therefore also the dipole pairs with RMSDIF within 1% difference from the best solution were accepted and analyzed. From the obtained group of accepted dipole pairs two clusters of dipoles were created by applying the K-means iterative algorithm for K=2 based on Euclidean distance between the dipoles [6]. The final gravity centers of both clusters were marked as the centers of identified lesions. Because each dipole from inversely computed dipole pair should represent one of the two original ischemic lesions, we should be able to divide all accepted dipoles to 2 different clusters. If there exists a dipole pair whose members cannot be split into two different clusters it is rejected from clusterization. The solution with rejected dipole pairs cannot reliably identify two ischemic lesions. To decide whether the obtained clusters really represent two separate lesions, the following criteria were used for each particular DIM: First, it should be possible to divide all accepted results into 2 clusters, second the mutual distance between the clusters' centers should be more than 3.5 cm [4].

The method was applied on realistically shaped torso model surrounded by a nonconductive medium. In inhomogeneous torso model, analytically shaped heart model with two ventricles' cavities filled with blood (modeled by ellipsoids) and realistically shaped lungs were considered. The conductivity of the blood was considered to be 3 times higher and the conductivity of lungs was supposed 4 times lower than the mean conductivity of the torso. In homogeneous torso model only the mean conductivity of the torso was considered. The inverse solution was computed for dipoles located in the same 168 positions for both cases.

To model double lesions, combinations of two lesions of the same size at different locations were used. For the sizes S, M and L, 12 combinations were used, and for the size XL, 24 combinations of two ischemic lesions were modeled. The corresponding DIMs were computed in 64 points on the torso surface representing the leads of the modified Amsterdam lead system generally used in real measurements [6]. The results obtained from inverse solution to two dipoles using homogeneous and inhomogeneous torso model were evaluated according the aforementioned criteria and compared.

## 3 Results

The inverse solution to two dipoles was computed using both, homogeneous and inhomogeneous torso model. First, for each computed DIM, representing a simulated double lesion, the best location of a representative dipole pair was found according the criterion of the minimal RMSDIF between the original DIM and the inversely estimated dipole pair. The values of minimal RMSDIFs computed for each DIM in 6 sets of various lesions size using both torso models were then compared. The mean RMSDIFs computed for the best inversely estimated dipole pair for each size of lesions are summarized in Fig.2.

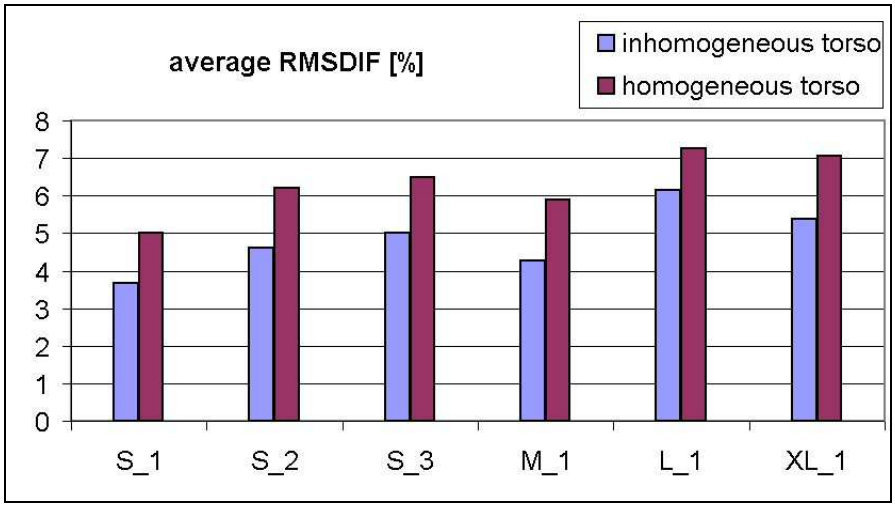


Fig 2.Mean relative differences averaged for each set of double lesions for their best inversely estimated dipole pairs representation for the cases of inhomogeneous and homogeneous torso.

For all sizes of lesions the value of RMSDIF was higher for homogeneous torso model than for inhomogeneous one, the difference was from 1.1% to 1.7%.

Then, for each DIM the dipole pair with the smallest RMSDIF value together with dipole pairs with RMSDIF within 1% difference from the best solution were accepted and clustered into 2 groups.

Then the properties of clusters were analyzed and evaluated whether they represent two different lesions. For every type of a double lesion only those cluster pairs were accepted as a good result (correctly identified case), where all dipole pairs were split into the two clusters and the mutual distance of the clusters was more than 3.5cm. Such results identified two separate lesions. Other results were regarded as not reliable, either due to insufficient mutual cluster distance or due to not unique dipole pairs' division. The portion of correctly identified cases for each size of lesions is depicted in Fig.3.


Fig 3.The number of correctly identified cases with 2 lesions related to the number of all simulated cases in each set expressed in % for both torso models.

For inhomogeneous torso model we were able to identify all cases with 2 lesions for 2 sets of simulations (for lesions with size S_1 and M_1). In other sets some cases were not identified as two lesions – from 8.3 to 16.7% what corresponds to 1 or 2 cases from 12 modeled. For homogeneous torso model from 8.3 to 25 % of cases were not identified what represents up to 3 cases from 12.

Finally the localization error defined as the distance between the gravity center of the modeled lesion and the centre of the nearer cluster considered as representative of this lesion was evaluated. The results are shown in Fig.4.

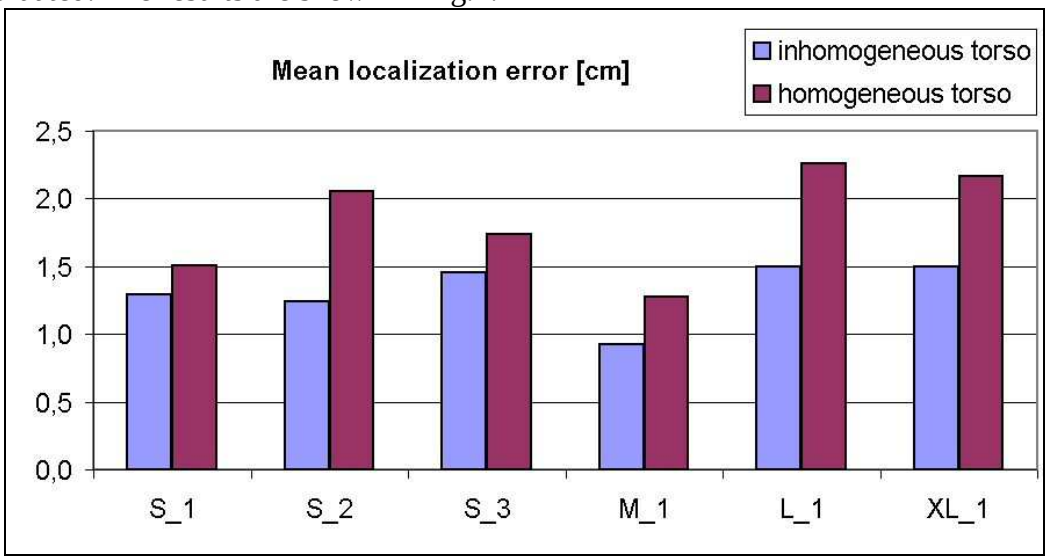


Fig 4.Mean localization error between the centres of modeled lesions and their inversely estimated positions for 6 sets representing 6 sizes of lesions.

The mean localization error for inhomogeneous torso varied from 0.9cm (for size M_1) to 1.5cm (L_1, XL_1) while for homogeneous torso the values oscillated from 1.3 to almost 2.3cm.

## 4 Discussion

In this study we compared the results of inverse solutions to two dipoles computed from the same input DIM using inhomogeneous and homogeneous realistically shaped torso model. Six sets of DIMs simulated from 6 sets of various combinations of 2 simultaneous ischemic lesions located on anterior, posterior or inferior side of left ventricle were used. Each set contained the pairs of equally large lesions.

First, the ability of inversely estimated dipole pair to reconstruct the input DIM expressed by RMSDIF was evaluated. For inhomogeneous model the RMSDIF was smaller than for homogeneous one by 1.5 % on average.

Then the success in identification of modeled lesions was observed comparing the number of identified cases to all modeled cases. Except the set of size S_3 the average number of correctly identified cases was always greater for inhomogeneous torso.

Finally the mean localization error was smaller for inhomogeneous torso for all simulated sets of DIMs by almost 0.5cm on average.

For all observed aspects of obtained inverse solutions we got better results using the inhomogeneous torso model. This means that for solving the inverse problem in electrocardiography also information about the most important torso inhomogeneities is desirable in addition to the appropriate number of measuring leads and the basic configuration of the torso.

Although the use of homogeneous torso model yields to worse results they do not differ substantially and allow to identify most of the modeled lesions. It should be noted, that in the presented study the inverse solution for both torso models was computed to the predefined positions located in the modeled myocardium. It means, that the correct position of the heart was supposedly known. One can expect that the localization results can be influenced by the accuracy of information about the mutual position of the heart and torso.

## 5 Conclusions

In this simulation study homogeneous and inhomogeneous torso models were used for inverse identification and localization of two simultaneous ischemic lesions by solving the inverse problem of electrocardiography from difference integral map. Better results were obtained when appropriate electric conductivities of internal organs surrounding the heart were used.

## Acknowledgement

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