ADAPTATION OF THE POSITION OF THE STANDARD HEART MODEL USING MULTI-LEAD ECG

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Abstract: The solution of the inverse problem of electrocardiologie relies on the correct placement of the heart in the thoracic cage. For its optimization it is proposed to use information obtained from multiple ECG leads. The results of this study show that as a reference point for this task can be used the position of the dipole representing the activation of cardiac ventricles in the course of the first 20 ms of the QRS complex.

Keywords: heart position, multiple leads ECG, inverse problem, computer model

1. INTRODUCTION

Solving the inverse problem of electrocardiology provides valuable information about the heart on hand of potential data measured from the surface of the chest using multiple ECG leads. It can be used for example to locate ischemic lesions or determine the positions of other kind's of abnormalities in the proceeding of the heart's electrical propagation. However the accuracy depends on the degree of anatomical similarity between the considered computer torso model and the real situation in the measured subject. One of the most important aspects is the position of the heart.

Using magnetic resonance imaging (MRI) [1], [2] it became evident, that the interindividual position of the heart varies greatly. In that study, the localization of the heart was evaluated relatively to the position of lead V2 of the standard 12-lead system, which is usually placed in the fourth intercostal area to the left from the sternum. The positional variability of the heart was observed mainly in the vertical direction.This interindividual variability is usually not taken into account in studies using standard computer torso models.

The method proposed in this paper is an attempt to use the ECG signals of a measured subject to estimate the real position of his heart. The precondition is taken, that it is possible to represent the beginning of the ventricular activation with one dipole identified by solving the inverse problem of electrocardiography from an integral map of a properly selected interval shortly after the beginning of the QRS complex. It is presumed that the position of this dipole is related to the real position of the heart.

2. MATERIALS AND METHODS

The ECG signals and geometrical data used in this study were obtained in The Department of Medical Physics of the University of Amsterdam [1], [2]. A system of 62-leads (62 + 2 limb leads) was used to obtain ECG signals from the surface of the chest of 25 healthy subjects. The placement of the electrodes was in relation to the standard position of the lead V2. A 10 s signal with a sampling frequency 1 000 Hz was recorded. Using the MRI (1.5 T Siemens Magnetom SP MRI) geometrical models of the chest, lungs, myocardium and cavities of the heart ventricles were obtained. Also the position of measuring electrodes was recorded. The standard computer model designed in Dalhousie University, Halifax, Canada [3] was used in this study with a small modification.

In the signal preprocessing the fluctuation of the isoline and the 50 Hz network interference were removed using the Lynn cut filter and Pipberger filter. To eliminate the myopotentials, an average heart cycle was calculated for each signal with the help of a cumulation method [4]. Finely by forcing the PQ interval of each average cycle in every lead to zero the remaining diversion of the isoline was also removed.

In these edited ECG signals the onset of ventricular depolarization (QRS complex) was determined manually for each subject from the root mean square (rms) calculated for each time instance of an average cycle from all 64 leads according to:

$$rms_t = \sqrt{\frac{\sum_{n=1}^{64} x_{nt}^2}{64}} \, . \tag{1}$$

Where x_n is a sample in lead n in the time instance t_i.

Subsequently, integral maps [5] over five chosen intervals (Table 1) from the first 20 ms after the beginning of ventricular depolarization (t_Q) were computed according to the equation:

$$imapa_{el} = \frac{\sum_{i=1}^{N} x_i}{N} \, . \tag{2}$$

Where $imapa_{el}$ is the value of the integral for the lead el and x_i is a sample in the time instance t_i of the selected interval. The step of the used discrete integration can be in this case considered as 1. The integration is divided by the number of samples N to normalize the integral maps computed from intervals of different lengths (5 ms and 10 ms).

t_1 [ms]	t_Q	t_Q+5	t_Q+5	t_Q+10	t_Q+10
t_2 [ms]	t_Q+10	t_Q+10	t_Q+15	t_Q+15	t_Q+20

Table 1: Intervals used for computing of the integral maps: t_Q beginning of the ventricular depolarization; t_1 star of the interval; t_2 end of the interval [5].

From the above mentioned integral maps the inverse problem was solved into one dipole, calculated into a predefined position (“Jumping Dipole Method”) [6]. This was made for the homogeneous torso model of a concrete patient obtained from MRI images as well as for the standard model. Hereby, the position of a dipole whose vectors value and direction best represents the input integral map is the solution of the inverse problem. The dipole is calculated from this equation:

$$\tilde{G}^j = \left[A^j\right]^{-1} * \Phi \, . \tag{3}$$

Where $\tilde{\mathbf{G}}^j$ represents the calculated dipole j, $[\mathbf{A}^j]^{-1}$ is the pseudoinverse matrix of the transmission matrix $\mathbf{A}^j$ which represents the relationship between the heart dipole in position j and potentials on the surface of the chest and $\mathbf{\Phi}$ is a vector of the measured surface potentials.

Since the position of the dipole is being searched among a grid of predefined positions the accuracy of this localization depends on the space between individual points of this grid. For the localization of the dipole a grid was used with the distance between the points of 3 mm, hence a maximum error of 1.5 mm.

Evaluation of the Euclidean distance of the calculated results from the chest lead V2 (Figure 1) showed a high level of correlation between the results from individual torso models and the standard model (corel. coef. = 0.90).

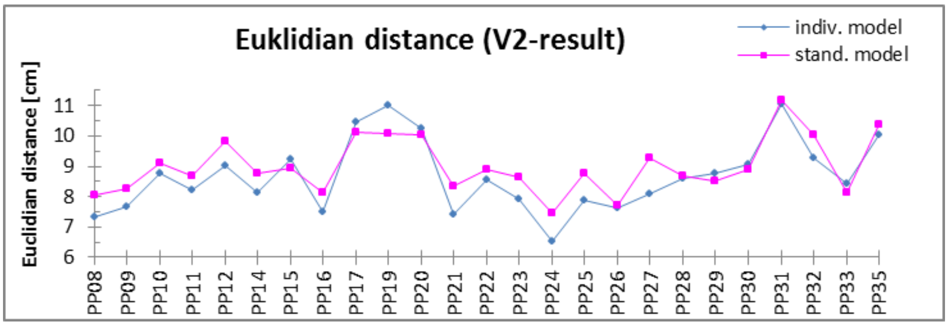

Figure 1: Graph of the Euclidean distance between the lead V2 and the results of the inverse problem for individual patients (marked PPxx) in individual models and in the standard model [5].

Even a better correlation (corel. coef = 0.94) shows in the vertical direction (Figure 2).

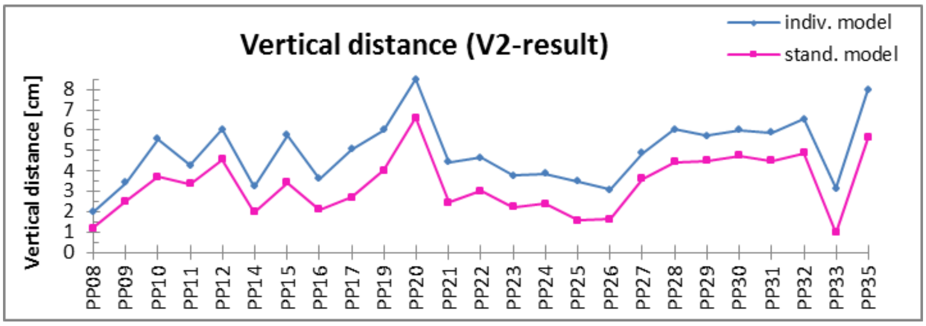

Figure 2: Graph of the vertical distance (axis z) of the results of inverse problem from lead V2 for individual patients (marked PPxx) in individual models and in the standard model [5].

However the results of the vertical correlation show a systematic error of approximately 1 cm which appears also in most cases of the front-back direction (axis x), but does not appear in the case of Euclidean distance. The correlation coefficient in the direction of axis x is of just 0.80 and in the direction of axis y 0.92.

If V2 is taken for a reference point based on this results (Figure 2 and 3) a conclusion can be made, that the results in the standard model correspond to a certain extent with the position of the results in the real models. Based on this, it should be possible to determine the real position of the heart in the chest of a real person if the position of the dipole representing the beginning of the ventricular depolarization can by localized in the standard model and it is known where this point should be located in the heart from the anatomical point of view.

The position of the dipole was determined by solving the inverse problem from integral maps of the selected 5 time intervals by all 25 individual models. Subsequently, the final location of the beginning of the depolarization was obtained by averaging the coordinates of these dipoles. A common anatomical reference point (RP) was selected to represent this position in all models at the same anatomical reference to the models and to be able to choose an anatomically equivalent reference point for the standard heard model (RP_st). The reference point is located [5] on the surface of the left heart ventricle in the region of transition of the septum in the back wall of the heart.

3. ADDAPTATION OF THE HEART MODEL POSITION

The principle of the method lies in computing of the difference between the reference point and the position of the result of the inverse problem determined from the integral map of a concrete person in the standard model and subsequently shifting all points of the standard heart model by this value. This approach was tested in the direction of all axes (x, y, z) and in the vertical direction (axis z).

The proposed method was evaluated by comparing the distance of the reference point from V2 in the case of the concrete models and the distance of RP_st from V2 before and after moving the standard heart model. After shifting the heart in all axes direction becomes the difference of the Euclidean distance of RP from V2 and RP_st from V2 reduced from an average value of 0.2 cm to 0.1 cm, which is a small improvement. Unfortunately the standard deviation increases from 1.3 cm to 1.5 cm. The best results showed by moving the heard model in the vertical direction (axis z). The average value of the difference decreases from 3.7 cm to 1.9 cm and the standard deviation also decreases from 2.2 cm to 1.9 cm. In the direction of axis x the value of the difference changed from -1.7 cm to -1.2 cm (standard deviation from 1.0 cm to 1.3 cm). And in the horizontal direction of axis y it decreases from -1.1 cm to -0.5 cm (standard deviation from 0.9 cm to 1.0 cm).

The relative low improvement in the similarity of the distance of RP from lead V2 and the distance of RP_st from V2 achieved by 3D movement of the heart model is shown on Figure 3.

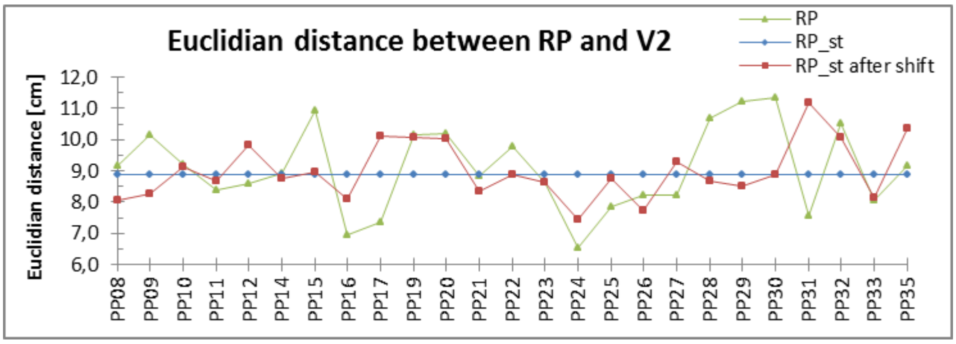

Figure 3: Comparison of the Euclidean distance of the reference point RP from V2 in the case of individual models and of the distance RP_st from V2 in the standard model before and after the 3D shifting of the heart model for all 25 subjects (marked PPxx) [5].

The by far better results of the heart shifting in just the vertical direction (axis z) for each person are on following Figure 4.

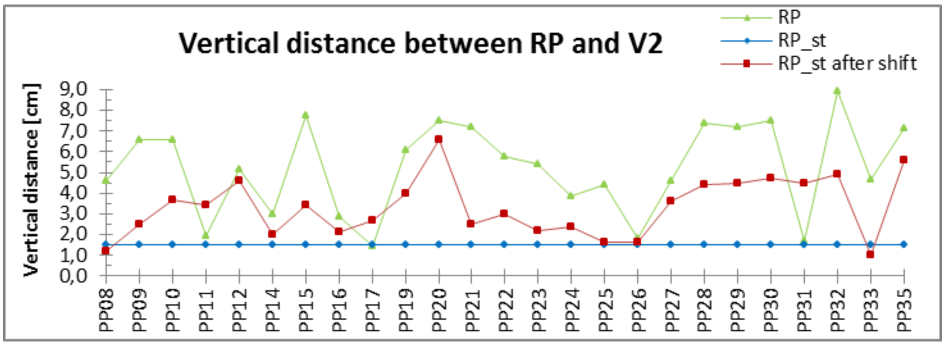

Figure 4: Comparison of the vertical distance of the reference point RP from V2 in individual models and of the distance RP_st from V2 in the standard model before and after shifting the heart model in the vertical direction for all 25 subjects (marked PPxx) [5].

It is clearly visible that in most cases is an improvement of the correspondence of vertical position of the heart in the standard model to the placement of the heart in the real individual chests after adjusting the standard model. A significant deterioration was visible just in the case of patient PP11, PP17 and especially PP31, by who the dipole representing the beginning of the activation of the heart ventricles was found outside of the given concrete heart model.

4. DISCUSSION

The proposed method assumes that the dipole representing the beginning of the ventricular activation is located in the chosen reference point of the heart model (RP for the concrete and RP_st for the standard). This causes a methodical error given the fact that the real position of the dipole varies. The velocity of it approximately corresponds to the average distance of the given reference point to the result.

Although there was some improvement in the localization of the heart in the standard thorax model achieved, mainly in the vertical direction a large error of almost 2 cm appears. In this direction a systematic error of approximately 1 cm is evident (Figure 2). The most likely reasons are a large variability in the thorax geometry of each subject, follows a significant difference in the electrode layout. Not to forget the differences in the internal geometry and the conductivity of its individual structures. Also it was observed a significant variability of the location of the dipole representing the beginning of the ventricular activation. This is most likely due to the interindividual variability of the activation sequence. Another factor is the rotation and slope of the heart causing differences of vectors of individual electrodes on the thorax surface and due to this an unquantifiable error.

This method assumes a normal propagation of the ventricular depolarization and therefore it cannot be used in the case of an abnormal pathological activation.

5. CONCLUSIONS

According to the results it is possible to adjust the position of the heart model in the standard thorax model just with the help of information's from ECG signals measured on a studied subject using the proposed method. Hereby the best results show after shifting the heart model in the vertical direction. Nevertheless a significant error of around 2 cm appears in this direction and has to be taken in to account. Better result could be achieved by adding additional information about the patients' thorax such as its external dimensions, the layout of the mapping electrodes and the rotation and slope of the studied patient heart.

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