LOCALIZATION OF ACCESSORY PATHWAY IN THE HEART USING BODY SURFACE POTENTIALS

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Abstract

Results of noninvasive localization of arrhythmogenic tissue in the heart are presented. Location of the accessory pathway in preexcitations was estimated by inverse computations using body surface ecg potentials from limited number of leads, approximate geometry of the patient torso and multiple dipole model of cardiac electric generator. The method was first tested on simulated ecg data and influence of error factors such as noise in ecg potentials, use of limited number of measured leads, computations using simplified homogeneous torso model or inaccurate knowledge of heart position was evaluated. Then ecg potentials measured from 24 leads in 9 patients who later underwent successful radio-frequency catheter ablation of single accessory pathway were submitted to the localization procedure. In simulated ecg data, mean localization error of 1.7 cm and success rate of 86 % was obtained under realistic measurement conditions when using 63 leads, while 2.2 cm error and 62 % success was achieved when using only 24 leads. In measured ecg data from 24 leads, the site of accessory pathway confirmed by successful ablation was located in 78% cases into the correct or neighboring heart segment and in 22% cases the localization failed.

Keywords: body surface potential map, localization of arrhythmia in the heart, multiple dipole model, rf ablation of accessory pathway

1. Introduction

Surface ecg potentials measured from 12 standard leads are routinely used for preliminary localization of pathological activation sites in the human heart before rf catheter ablation (RFCA) treatment. It is widely recognized that body surface potential (BSP) maps can improve the localization in some cases and that model-based inverse techniques using the patient's body surface potential maps and torso geometry can also help to solve the localization problem. One of the questions still opened is what accuracy can be expected when using particular inverse solution.

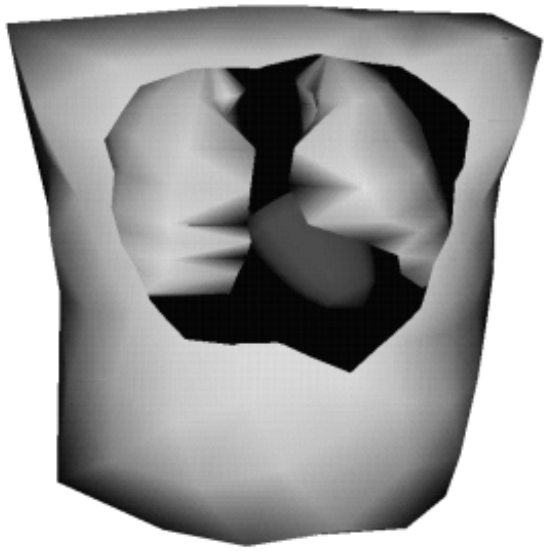
In this study, the accuracy of a non-invasive localization of single accessory pathway based on multiple dipole model of the cardiac generator was first examined on well defined simulated ecg data and realistic torso model and then the procedure was tested on real BSP measurements from a group of patients who underwent successful RFCA treatment of single accessory pathway (AP).

2. Method

Locations of the AP were estimated by inverse computations using BSP measured in limited number of leads. Approximate realistic geometry of the patient torso and multiple dipole (MD) model of cardiac electric generator were used in the computations.

The geometry included shape of torso, lungs and heart (Fig. 1) and main electrical inhomogeneities (lungs and heart cavities filled with blood) were considered. The same realistic torso model and approximate heart position was used to approximate the torso in all patients.

Figure1. Realistic inhomogeneous torso model includes torso



shape, lungs and analytic or realistic heart model.

The MD generator with 39 dipoles in fixed positions relative to the heart was used as the equivalent cardiac electric source. Each dipole represented activation of corresponding heart segment (Fig.2). In our model, the AP was located in the middle of one of 16 segments along atrio-ventricular (AV) ring.

Maximal integral of segmental dipole moment $\boldsymbol{M}$ computed over the initial 25 ms of activation was used as criterion to detect the segment with earliest activation belonging to the AP.

Segmental dipole moments $\boldsymbol{M}$ were estimated from surface potentials $\boldsymbol{\Phi}$ using the formula $\boldsymbol{M}=\boldsymbol{T}^{+}\boldsymbol{\Phi}$, where

T^+ is the pseudo-inverse of the transfer matrix T obtained by truncated singular value decomposition. T represents the relation between segmental dipoles and patient torso geometry [1].

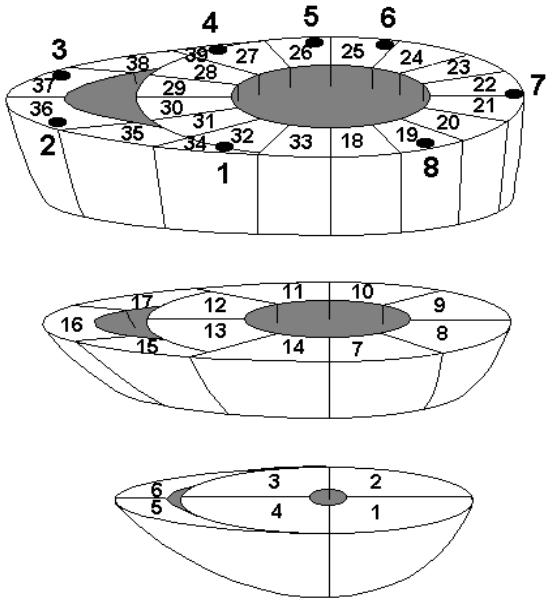


Figure 2. Heart model with 39 segments, 16 of them on the AV ring. Locations of simulated accessory pathways are marked on the AV ring: antero-septal (1), anterior RV (2), lateral RV (3), posterior RV (4), postero-septal (5), posterior LV (6), lateral LV (7) and anterior LV (8).

Localization error of each inverse calculation was computed as the distance between the center of the segment identified by the inverse solution (and projected onto the AV ring circumference) and the a priori defined position of the starting point of activation used in the forward simulation. In our heart model, the length of heart segments on the AV ring was 1.3 to 2.2 cm (mean 1.54 cm). Localization errors greater than 3 cm were considered as localization failures.

The method was first tested on simulated BSP. Possible errors in input data, namely noise in the input ecg potentials, use of limited number of ecg leads, computations in simplified homogeneous torso and inaccuracy of the position of the equivalent generator, were analyzed as factors influencing the accuracy of the localization. Synergetic effects of these factors were also analyzed.

To get simulated ecg potentials, a finite element model of heart ventricles [2] as shown in Fig. 2 was used to generate activation sequences, each initiated in single site on the AV ring. Using boundary element method, corresponding ecg potentials were computed in surface points of an inhomogeneous torso model with lungs and cavities and with the MD generator located in the exact heart position. The same torso geometry was used as in the inverse calculations. Simulated ecg potentials corresponding to excitations starting from 8 different accessory pathways were used as input data.

3. Results

The mean localization error (MLE) caused by the size of the heart segments would be 0,4 cm (if all 8 simulated APs were detected in correct segments) and represents the resolution of our method. Actual MLE obtained when 198 surface potentials and inhomogeneous torso were used was 0.7 cm and different error factors in input data caused its increase up to 6.1 cm.

When homogeneous torso was used, the MLE reached up to 1.1 cm, for noise with σ up to 10 μV the MLE raised to 1.7 cm and stability of the solution decreased slightly. For noise levels higher than 10 - 15 μV the results were influenced significantly as shown in Fig. 3 and in several cases segments distant from actual initial activation site were identified.

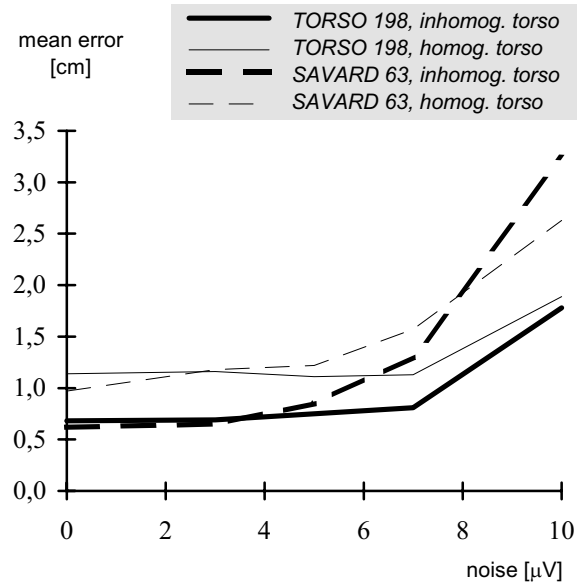


Figure 3: Influence of noise in input ecg data on the mean localization error when potentials simulated in 198 or 63 leads were taken as input data and inhomogeneous or homogeneous torso model was used.

To get the influence of limited number of measured surface potentials, several lead sets were tested: 63 leads (according to Savard), 32 leads (according to Lux) and 24 leads (according to Barr). The MLE was 0.7 - 6.1 cm and increased with decreasing number of leads. Results for different lead sets are summarized in Table 1.

Several shifts and rotations of the MD generator were simulated to estimate the influence of incorrect heart position knowledge. In cases where the sites of AP were moved approximately 1 cm from the correct position, MLE of 0.7 - 1.1 cm was achieved. For bigger displacements (about 2 cm) the MLE raised and significant deterioration of the results appeared more frequently.

ecg leads used in inverse computation	inhomog. torso		homog. torso	
	error [cm]	failures %	error [cm]	failures %
TORSO 198	0.7	0	1.1	0
SAVARD 63	0.6	0	1.0	0
LUX 32	1.9	25	1.2	0
LUX 32a	2.0	13	2.0	25
BARR 24	6.1	88	3.0	38
150 from BARR 24	3.3	63	3.0	38

Table 1: Mean localization errors and occurrence of localization failures in computations from different lead sets supposing inhomogeneous or homogeneous torso.

When all the factors were combined, noise with $\sigma \leq 5\mu V$ and generator displacements < 1 cm were acceptable to get an overall MLE of 1.1 to 2.8 cm (for 198 and 24 leads), however, in 0.5 - 35 % of simulated cases the localization failed.

The results of the simulations showed that the inverse procedure was able to reveal the locations of AP with acceptable accuracy even if a limited number of leads and simplified torso structure were used. As optimum, 63 leads should be measured to get MLE of about 1.7 cm and less than 14 % of localization failures under realistic measurement conditions as shown in Table 2. The need of precise knowledge of the patient geometry seemed to be important limitation for practical use of the method.

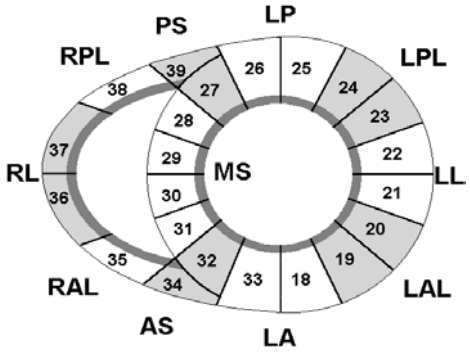
ERROR FACTORS in simulations	mean localization error [cm] (failures in %)	
torso model	homogeneous	inhomogeneous
no (8 cases)	0.6	1.0
noise 5 mV (40 cases)	0.9	1.2
MD moved (40 cases)	0.9	1.2 (2.5 %)
MD moved + noise (200 cases)	1.5 (8 %)	1.7 (14 %)

Table2. Results of simulated localization from 63 leads influenced by different error factors.

In subsequent experimental study, BSP from 9 patients (3 male, 6 female, age 18 to 51) who later underwent successful RFCA treatment of single AP were submitted to the non-invasive localization [3]. The BSP were measured in Bratislava (5 patients) and in Vienna (4 patients) by the ProCardio mapping system developed in the Institute of Measurement Science, Slovak Academy of Sciences [4]. For practical reasons, 24-lead system according to Barr with 20 anterior and 4 posterior electrodes was used. In 5 patients, basic torso dimensions were measured and used to compute a similarity index between the individual patient geometry and the torso model used in inverse computations. No geometry data were available for the other 4 patients.

Successful RFCA indicated left lateral (LL) AP in 4 patients, left antero-lateral (LAL) AP in 2 patients, left postero-lateral (LPL), right lateral (RL) and mid-septal (MS) AP in 1 patient.

Results of the localization using an "analytical" heart model are summarized in Table 3. The AP was located in 45% cases into the correct segment, in 33% cases into the first and in 22% cases into the second neighboring segment and no localization failed.



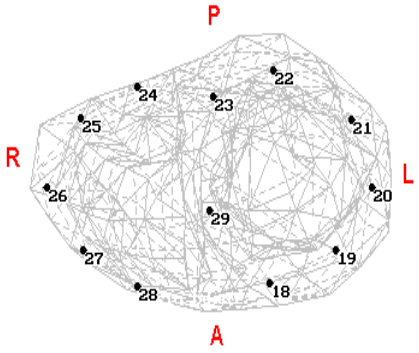
patient	similarity index	AP site	correct segment	localized by MD
FA45	0.88	LPL	23-24	21 *
F460	1.02	LL	21-22	21
F530	1.03	LL	21-22	19 *
F780	1.06	LL	21-22	21
AF49	0.82	LAL	19-20	20 *
BISC	-	LL	21-22	21
SCHN	-	LAL	19-20	21 *
FICH	-	RL	36-37	35
BICH	-	MS	28-31	35 *

Table 3: Results of localization in the analytically defined heart (above) using MD model. In cases marked with * the second or third maximal dipole (first located in the AV plane) was taken.

Results with a "realistic" heart model are shown in Table 4. The AP was located in 22% cases into the correct segment, in 56% cases into the neighboring segment and in 22% cases the localization failed. The localization results were less satisfactory in patients with torso shapes more different from the used torso model.

4.Discussion

Performance of the localization method was partially dependent on parameters used in the inverse computations, namely on preprocessing of ecg signals, on selection of evaluated time instants or intervals and on additional constraints put on the solution.



patient	similarity index	AP site	correct segment	localize by MD
FA45	0.88	LPL	21	21 +
F460	1.02	LL	20	21
F530	1.03	LL	20	19 *
F780	1.06	LL	20	21
AF49	0.82	LAL	19	28
BISC	-	LL	20	26
SCHN	-	LAL	19	19 *
FICH	-	RL	26	25
BICH	-	MS	29	28

Table 4: Results of localization using the realistic heart model. In case marked by * second maximal dipole (first in AV plane) was taken, in case + individual time interval was used, failures of localization are shaded.

Several methods of ecg preprocessing were tested to optimize performance of the localization method. As there is always some noise in ecg signals in practical situations, results for two types of moving average type filters and Pipberger low pass filter with 50 Hz notch were compared. Their influence was not substantial when interval 25ms on longer was evaluated and the last mentioned filter was finally used in the study.

Another parameter was the time for evaluation of the segmental dipole moments. In our simulations, time instants between 10 and 35 ms after the activation onset were evaluated. In most cases the maximal dipole moment criterion was pointing to the same segment over the whole interval. However, in some simulations the pointed segment changed during this interval. To improve the stability of the solution in such cases, maximal time integral of the dipole moment over the evaluated time interval was finally used as the criterion for segment identification. Length of the interval was set to 25 ms (which is also in correspondence with approaches already used on real data). Shorter intervals were more sensitive to noise in ecg and further prolongation of this interval did not improve localization results and could also hit the starting normal activation in other areas of the heart. However, localization at standard 25 ms interval failed in one patient from our study group, while individual time integral until the end of delta wave gave correct result. This indicates that individual selection of evaluated time interval would probably improve the localization results in some patients.

In several patients the maximal integral of segmental dipole moment pointed to a segment not on AV ring. In these cases 3 segments with biggest dipole moments were inspected and the first segment on AV ring was accepted as the AP location. This modification of the method improved the accuracy also if potentials from limited lead sets were used.

It is worth to mention that similar results were obtained when homogeneous or inhomogeneous torso model were used in the inverse calculations. The number of localization failures did not increase when the inhomogeneities were neglected.

5. Conclusions

The presented results indicate that the model based non-invasive inverse localization was in most cases able to determine the position of the AP within 11 or 12 regions on the AV ring. The success rate was in correspondence with the results obtained in the simulation experiments. From the simulations it also follows that 63 or more leads and individual torso geometry should be tried to improve the localization accuracy.

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References

[1] R.M. Gulrajani, F.A. Roberge, P.Y. Savard Eds., Comprehensive Electrocardiology, chapter 10, Inverse Problem of Electrocardiology. Pergamon Press, New York, 1989: 250-300.

[2] V. Szathmáry, R. Osvald: An interactive computer model of propagated activation with analytically defined geometry of ventricles. Computers and Biomed. Res, 27: 27-38, 1994.

[3] M. Tyšler, M. Turzová, J. Švehlíková, M. Tinová, K. Kozlíková: Noninvasive localization of preexcitation sites using experimental BSPM data. In: Electrocardiology '97, Singapore, World Scientific, 1998 (in press).

[4] V. Rosík, M. Tyšler, M. Turzová: PC-based device for ECG mapping. Biomediziniscshe Technik, 42, Ergänzungsband 1: 159-162, 1997.