NONINVASIVE LOCALIZATION OF CARDIAC ARRHYTHMIAS

M. Tyšler, M. Turzová, M. Tiňová and P. Kneppo

Institute of Measurement Science SAS, Bratislava, Slovak Republic

Email: umertysl@savba.sk

Abstract: Two methods for noninvasive localization of accessory pathway in WPW syndrome were proposed. They use measured surface ecg potentials, approximate torso geometry and multiple dipole or "jumping dipole" model of the cardiac electric generator. On simulated data the influence of noise in ecg, limited number of ecg leads, simplified torso structure and inaccurate knowledge of heart position was evaluated. Under realistic conditions, mean localization errors of 1.7 and 1.1 cm were obtained for the two models. In a patient with 63 measured ecg leads and torso geometry obtained by CT the localization was successful by both models. In 9 patients where 24-lead ecg and model torso was used, the localization was successful in 8 and 7 cases.

Introduction

Some types of cardiac arrhythmias are initiated in a small confined region of heart. This is also the case of a Wolff-Parkinson-White syndrome (WPW) when some pathological conductive tissue called accessory pathway (AP) exists in the atrio-ventricular (AV) area of the heart. Noninvasive preoperative localization of the AP site from measured body surface potentials (BSP) can be useful for guiding the catheter during the radio-frequency ablation (RFCA) of the arrhythmogenic tissue. In most WPW patients single AP occurs which can be approximated by a dipole located at that region. In this study, two methods for noninvasive localization of AP based on dipole models were tested: accuracy of both methods was first examined on simulated data and then the procedures were applied to a group of WPW patients with single AP.

Methods and Materials

To find the position of AP on the AV ring, two types of generators based on current dipole sources were considered as models of real cardiac electric generator. In *multiple dipole* (MD) model the components of simultaneously activated segmental dipoles located in centers of predefined cardiac segments were inversely calculated during the preexcitation interval. Maximal dipole moment was used as criterion for identification of the segment with AP. To stabilize the solution, dipole moments were integrated over selected time interval [1].

In *jumping dipole* (JD) model, single best fitting dipole located in the center of each heart segment was inversely estimated from BSP. For all estimated segmental dipoles, corresponding surface potentials were computed and compared with the original BSP. The AP was localized into the segment with minimal relative rms error between the original and computed BSP over a selected time interval [2].

The same heart segmentation into 39 ventricular segments was used in all experiments (Figure 1).

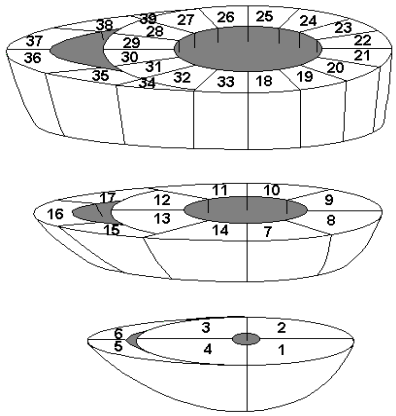

Figure 1: Segmentation of analytically defined heart ventricles used for inverse localization of AP.

To test the localization procedures, AP in different regions along the AV ring of analytically defined ventricles were simulated and corresponding BSP were computed in a realistic inhomogeneous torso model. Using the simulated BSP, influence of different error factors on the inverse localization of AP was analyzed. Limited number of 24 to 63 ecg leads was used instead of a full set of 198 BSP values, noise of 3 to 20 μV was added to simulated BSP, misplacements of the AP of about 1 cm were introduced by shifts and rotations of the cardiac generator. Incomplete knowledge of the thorax structure was simulated by use of homogeneous torso. The localization error (LE) was evaluated as the epicardial distance between the center of identified heart segment and the actual AP site. Cases with LE greater than 3 cm were regarded as localization failures.

Data from 10 WPW patients with single AP confirmed by successful RFCA in one of 11 physiologically defined regions on AV were submitted to the localization procedure. In 9 patients 24 measured

ecg leads and common geometry (the same as in the simulations) was used. In 1 patient, 63 ecg leads and torso geometry obtained from CT were available.

Results

Results of AP localization from simulated BSP using different ecg lead systems are shown in Table 1. When only 24 BSP were used, localization using the MD model brought unsatisfactory results: the mean LE reached 3 cm and the localization failed in almost 40% of cases even if only segments on AV ring (*with second or third biggest dipole moment) were accepted.

Table 1: Influence of lead system on the mean LE when inhomogeneous or homogeneous torso model was used.

Lead system and Number of leads	Mean localization error [cm]			
	MD model		JD model	
	Inhomog.	Homog.	Inhomog.	Homog.
Torso 198	0,6	1,1	0,5	0,6
Savard 63	0,6	1,1	0,5	0,8
Lux 32	1.5	2.1	0.4	0.5
Barr 24	*3,2	*2,4	0,9	1,0

When AP was localized from 63 leads, acceptable results were obtained even if all error factors were combined (Table 2). The influence of inaccurate knowledge of heart position was similar for both models. On the other hand, influence of torso inhomogeneities and noise in ecg was higher in the MD model. No failures occurred with the JD model.

Table 2: Results of simulated AP localization from 63 leads influenced by different factors.

Error factors (Number of simulations)	Mean LE [cm] (Failures)	
	MD model	JD model
no (8)	0.6	0.5
homogeneous torso (8)	1.1	0.8
noise 5 μV (40)	0.8	0.5
heart misplacements (40)	0.9	1.0
combined factors (200)	1.7 (14 %)	1.1

From the 9 patients measured in 24 leads, in 5 cases maximal dipole was found out of the AV ring by the MD model. In these cases, segment on the AV ring with second or third biggest dipole moment was taken. After that, the AP was localized in 4 cases into the correct segment, in 4 cases into the first or second neighboring segment and in 1 case the AP localization failed. For the JD model, all APs were localized on the AV ring. Correct segment was identified in 4 cases, first or second neighboring segment in 3 cases and in 2 cases the detected segment center was more than 3 cm from the AP region estimated during RFCA.

For the patient with 63 measured ecg leads, different torso configurations were tested (Table 3). Both models were able to localize the AP within 1 or 2 segments if real inhomogeneous torso was used. With the JD model, proper AP site was localized even if approximate heart geometry and homogeneous torso model was used.

Table 3: Localized segments with AP in the patient with 63 ecg leads (actual AP site was in segments 19-21)

Geometry	MD model		JD model	
	Inhomog.	Homog.	Inhomog.	Homog.
real torso & heart	20	34	19	19
approximate heart	20	7	19	19
standard model	7	18	19	20

Discussion

In the simulations, optimal time intervals for evaluation were proposed for both models. However, in more patients from the study group, localization at standard time intervals failed, while individual intervals gave correct results. This indicates that individual selection of time intervals is necessary.

If low number of BSP (24 leads) was available, use of inhomogeneous torso did not improve LE when compared to results obtained with homogeneous torso.

Position of the AP in WPW patients was determined during RFCA only approximately in one of 11 AV regions. Therefore LE could not be evaluated.

Conclusions

Presented results indicate that both JD and MD models were able to determine the position of AP within one of 11 regions on the AV ring if 63 ecg were used. In most cases, even if only 24 leads were measured correct or neighboring segment was identified and the success rate was in correspondence with the results obtained in simulations. Generally, the JD model performed better and was less sensitive noise in ecg and geometry inaccuracy.

ACKNOWLEDGEMENTS

This work was supported by grant 2/5089/98 from the VEGA grant agency. The authors thank to Dr. Hatala, Dr. Kozlíková and Dr. Huiskamp for their patient data.

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