IDENTIFICATION OF LOCAL REPOLARIZATION CHANGES IN THE HEART BY AN INVERSE SOLUTION WITH TWO DIPOLES

Švehlíková J., Tyšler M., Turzová M., Hebláková E.

Institute of Measurement Science SAS, Bratislava, Slovakia
email: svehlikova@savba.sk

A method for noninvasive identification of local ischemia from surface difference integral maps by solving an inverse problem for two dipoles was proposed and tested on simulated data for 12 single lesions and 12 couples. Two-dipole equivalent generators were estimated using the criterion of minimal rms difference (RDIF) between the simulated map and map generated by the dipoles. Best dipole pair and clusters of dipoles with RDIF no more than 1% above the minimal one were evaluated as possible lesions positions. Nine of 12 couples of lesions were recognized, lesion localization errors were in 6 cases <1 cm, in 2 cases <2 cm and in 1 case 3.1 cm.

1. INTRODUCTION

Integral maps of the QRST interval represent distribution of cardiac potentials on the torso surface integrated over the whole cardiac cycle. Repolarization changes due to ischemia can be characterized by differences between maps obtained under normal conditions and conditions with manifestation of ischemia and can be visualized as a difference integral map (DIM). If the changes occur only in a small area, the electrical generator producing the DIM can be represented by single dipole. Previously we proposed a method for identification of one pathological area in the heart by using the DIM together with information on torso geometry and electrical properties and solving the inverse problem for single dipole [1]. In this study, possibility to identify cases with two small ischemic lesions by using a two-dipole inverse solution was analyzed on simulated ECG data.

2. METHODS

Isotropic myocardium model [2] with experimentally observed action potentials [3], multiple dipole cardiac generator and boundary element method were used to compute body surface potentials in 117 leads on a Dalhousie torso model [4] with main inhomogeneities (lungs, ventricular cavities).

Ischemic lesions were simulated by shortening myocytes action potentials by 20% in three myocardium areas typical for stenosis of main coronary vessels: in the antero-septal part of the LV near apex (lesion a), in the postero-lateral part of the LV close to the heart base (lesion p) and in the mid postero-septal part of the LV and RV (inferior lesion i). In each area, small, medium and large transmural subendocardial lesions (1, 2, 3) and one small subepicardial lesion (e) were defined. Besides these 12 cases, also combinations of two small lesions from different areas were used to get another 12 cases modeling couples of lesions.

Surface potentials and QRST integral maps were computed for the normal activation and for all 24 pathological cases. Corresponding DIMs were used to calculate inverse solutions with pairs of dipoles located in 168 points within the ventricles. The best pair – the winner - as well as pairs with RDIF within 1% from the best solution were analyzed. Two clusters of dipoles were created by applying the K-means algorithm [5] based on Euclidean distance between the dipoles. The gravity center of each cluster was considered as the center of one recognized lesion and the mean dipole moment computed from all dipoles in one cluster was assigned to that lesion.

For evaluation of the inverse solution and identification of double lesions, two criteria were used in this study: (1) number of dipoles in both clusters should be the same, (2) standard deviation of the orientation of dipole moments in the cluster should not exceed 20 degrees.

3. RESULTS

For all 24 pathological cases, the best dipole pair (winner) and all dipole pairs with RDIF differing less than 1% from the best value were computed. Both criteria for double lesions were fulfilled in 12 of 24 cases: 9 of them were couples of lesions and 3 were with 1 lesion.

Positions of dipoles in the inverse solutions with one dipole and with two dipoles were compared to check consistency of both solutions.

In the 9 cases with double lesions the inverse solution with 1 dipole was always located between the dipoles of the dipole pair or close to one of them (see example for lesions i1p1 in Fig. 1). For the 3 cases with one simulated lesion we got 3 various situations (Fig. 1): in case of lesion a3, the result for one dipole was on the other side of the left ventricle than either of the results for the 2-dipole solution, so we can assume that these results are not reliable and double lesion cannot be confirmed. In case of lesion ae, all resulting dipoles are consistently situated in a small area representing in fact the simulated lesion and we can conclude that the dipole pair represents only one lesion. In case of lesion p3 the result of the inverse solution with

1 dipole was situated between the dipoles of the dipole pair and the case looks like a reliable result for 2 adjacent lesions situated at the postero-lateral side of the left ventricle.

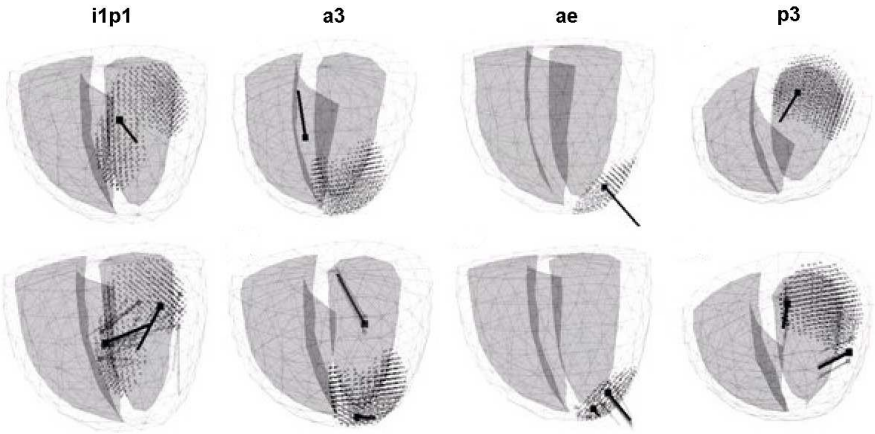

Fig. 1. Inversely estimated dipoles for 1 case with 2 simulated lesions (left) and 3 cases with 1 ischemic lesion identified as possible double lesions. Dotted areas in the ventricular model mark simulated ischemic lesions. Top: inverse solutions with single dipole. Bottom: inverse solutions with dipole pairs. Dipoles belonging to both clusters (light gray vectors) and the mean cluster dipoles (black vectors) are shown.

For the 9 correctly identified cases with double lesions, the location errors and the dipole orientation errors were computed. In 6 cases the location error was within 1.3 cm, in another 2 cases it was within 2.1 cm, only in 1 case the location error was 3.1 cm. The errors of dipole orientation were in most cases less than 20 degrees, in 2 cases they achieved 37 and 44 degrees. Examples of recognized couples of lesions are shown in Fig. 2.

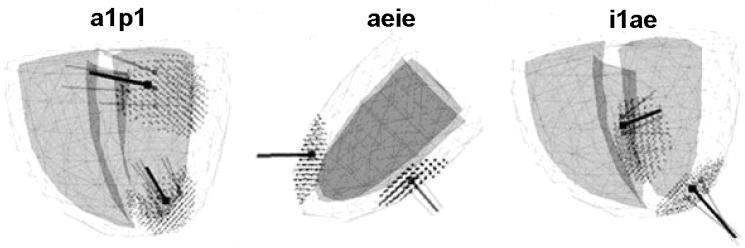

Fig. 2. Successful identification of double ischemic lesions by 2 dipoles. Left: two subendocardial lesions in anterior and postero-lateral part of the LV. Center: two subepicardial lesions on the anterior and inferior side of the LV (sagittal view). Right: combined subendocardial inferior and subepicardial anterior lesion in the LV.

4. DISCUSSION AND CONCLUSIONS

Errors of the inverse solutions with dipole pairs were computed for the winners as well as for the mean dipoles in clusters. Errors of the winners were about 20% greater what can be due to the restricted dipole locations.

Proposed inverse solution with two dipoles considering a set of "close to optimal" solutions seems to be a suitable tool for identification of possible double ischemic lesions and for evaluation of the reliability of the solution without an a priori knowledge about the existence of the two-vessel disease. However, the influence of noise in ECG signals, number of measured leads, geometry errors and other error factors were not examined in this study.

ACKNOWLEDGMENTS

This work was supported by grants 2/7092/27 from the VEGA grant agency and APVV-51-059005 from the APVV agency in Slovakia.

REFERENCES

1. Tysler et al.: Non-invasive Assessment of Local Myocardium Repolarization Changes using High Resolution Surface ECG Mapping. *Physiological Research*, 2007, vol. 56, Suppl.1, S133-S141.
2. Szathmary V., Osvald R.: An interactive computer model of propagated activation with ana-lytically defined geometry of ventricles; *Computers and Biomed.Research*, 1994, vol.27, 27-38.
3. Yan G.X. et al: Characteristics and Distribution of M cells in arterially perfused canine left ventricular wedge preparations, *Circulation* 1998, 1921-1927.
4. Horáček B.M. et al.: Optimal Electrocardiographic Leads for Detecting Acute Myocardial Ischemia; *Journal of Electrocardiology*, 2001, vol. 34, 97- 111.
5. Bishop Ch.M.: Pattern Recognition and Machine Learning; Springer 2006, 424 – 428.