Model-based Assessment of Local Ischemia - Criteria for Localization Credibility

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Abstract. *A method for noninvasive identification of local ischemic lesions from difference integral (DI) maps, based on dipolar representation of the lesion, was previously reported. Aim of this study was to find some criteria enabling to recognize DI maps representing large or multiple ischemic lesions when the dipole-based method is not suitable for ischemia localization and to estimate the level of noise in DI maps. One or two simultaneous ischemic lesions with different sizes and positions in the myocardium were modeled and corresponding DI maps were computed and contaminated by various degree of random noise. Relative difference between square values of dipole and dipole-and-quadrupole residual maps (shares of DI maps not represented by a dipole or dipole and quadrupole) was proposed to identify large or multiple lesions while mean square value of gradients in dipole residual maps was proposed to estimate the noise level. According to our simulations, these criteria can help to estimate the credibility of the noninvasive assessment of local ischemia.*

Keywords: *body surface potential mapping, dipole model of cardiac generator, noninvasive assessment of ischemic lesions*

1. Introduction

Previously we reported a model based inverse method for identification of local myocardial ischemia using differences in QRST integral maps obtained in conditions with and without ischemia manifestation. Equivalent dipole (ED) was used as a model of the cardiac generator representing changes of myocytes repolarization in the ischemic region and identifying possible position of the ischemia. Criterion for its finding was the minimal relative rms difference R_D between the original difference integral (DI) map and map generated by the ED:

$$R_D = \sqrt{\frac{\sum_i (D_i - O_i)^2}{\sum_i O_i^2}} \qquad (1)$$

where

- O values in original DI map of the lesion,
- D values in map computed from ED generator.

The summation was done over all mapped points on the torso surface and the criterion was evaluated for all possible ED positions.

Values of R_D can be understood as values of a criterion function with a minimum in position of the best ED. DI maps of large or multiple lesions or DI maps with high level of noise cannot be properly represented by single ED and R_D is supposed to reach higher values. Magnitude of R_D was therefore used as an indicator of credibility of the localization. However, according to our simulation experiments, localization error of the dipole increases substantially with growing extent of the ischemic region or when multiple lesions are present while it increases only slightly with bigger noise in DI maps. Mean localization error for (1) all ischemic lesions from maps without noise was 11.1 mm and increased to 13.3 mm when large noise of 4 mV.ms (rms) was added. In contrary, for small subendocardial and subepicardial lesions, the mean localization error was 8.9 mm and increased

to 17.5 mm for large transmural lesions even if no noise was present in DI maps (Fig.1) [2].

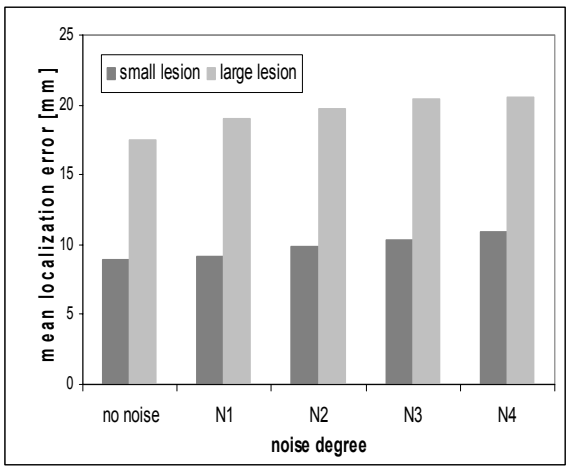

Fig. 1. Mean localization error for different sizes of ischemic lesions and its dependency on various degree of noise present in corresponding DI maps.

In this study, possible criteria for distinguishing between these two cases were investigated to assess applicability of the method for particular data and to estimate the reliability of the ischemia assessment.

2. Subject and Methods

Electrical activity of the heart, including its depolarization and repolarization phase during one cardiac cycle was simulated using a model of cardiac ventricles with analytically defined geometry [1]. Ischemic lesions were modeled by shortening of the normal action potential duration by 20% in three regions in heart ventricles usually influenced by stenosis of main coronary arteries: 1) in antero-septal part of the left ventricle near apex (anterior - A), 2) in postero-lateral part of the left ventricle close to the heart base (posterior - P) and 3) in mid postero-septal part of the left and right ventricle (inferior-I). One epicardial and three endocardial lesions of different sizes (3 - 12% of the ventricular volume) were created at each position. To simulate multi-vascular damage, combinations of two simultaneous endocardial lesions (A and P, P and I) were also modeled.

In forward computations [2], body surface potentials corresponding to normal and pathological repolarization were computed in 192 torso surface leads of a 16 x 12 mapping grid. DI maps representing differences between normal QRST integral maps and QRST integral maps with manifestation of ischemia were calculated. Several levels of noise (1, 2, 3 or 4 mV.ms, rms) representing random influences due to disturbances in the ECG signals (caused mainly by baseline shifts), were added to DI maps.

From simulated DI maps, corresponding ED source was inversely estimated for each vertex of the triangulated epicardial and endocardial surface [3]. Among them, best estimation of the ED was selected using the R_D criterion (1).

Two parameters were suggested to recognize whether the ischemic region is large (or fragmented) and the inverse method is not suitable for particular case or whether the data are only contaminated with higher level of noise.

The first parameter representing some measure of noise in DI maps was the mean square value of gradient of residual map – MSG, where the residual map was defined as the difference between a map generated by an ED and the original DI map (i.e. a residuum that the dipole was not able to represent):

$$MSG = \frac{\sum_i [grad\ (D_i - O_i)]^2}{m\,(n-1)} \qquad (2)$$

where

- m, n numbers of columns and rows in the mapping grid,
- O values in original DI map of the lesion,
- D values in map computed from the best ED generator.

Presuming that MSG represents local variations in the map, it should be little dependent on the size of the ischemic lesion and could help to distinguish cases where R_D reaches large values only because of noise

present in input DI maps while localization of the lesion still may be fairly reliable.

To recognize large or multiple lesions, multipolar representation of the source including equivalent dipole and quadrupole (EDQ) was used to comprise more complicated (but not random) character of the source representing the ischemic lesion. Value of relative rms difference R_{DQ} between the original DI map and map approximated by an EDQ generator can be understood as a part of the DI map that EDQ is not able to represent, particularly the noise. The difference between R_D^2 and R_{DQ}^2 thus can represent some non-random component in DI map that is not generated by single dipole:

$$QP = R_D^2 - R_{DQ}^2 = \frac{\sum_i (D_i - O_i)^2 - \sum_i (DQ_i - O_i)^2}{\sum_i O_i^2} \quad (3)$$

where

O values in original DI map of the lesion,

D values in map computed from ED generator,

DQ values in map computed from ED plus quadrupole generator.

This parameter was proposed to identify large or multiple lesions and was expected to be fairly noise independent.

3. Results

The average values of MSG for all types and sizes of lesions were 2.02, 5.76, 16.90, 35.38 and 61.06 for data with noise of 0, 1, 2, 3 and 4 mV.ms, respectively (Fig.2). MSG criterion achieved approximately 30 times greater value for DI maps contaminated with noise of 4 mV.ms than for simulated maps without any noise. The bigger was the noise, the better was the differentiation of particular level of noise contamination. Bar graph in Fig. 2 shows that MSG criterion was only slightly sensitive to the size or complexity (multiplicity) of ischemic regions.

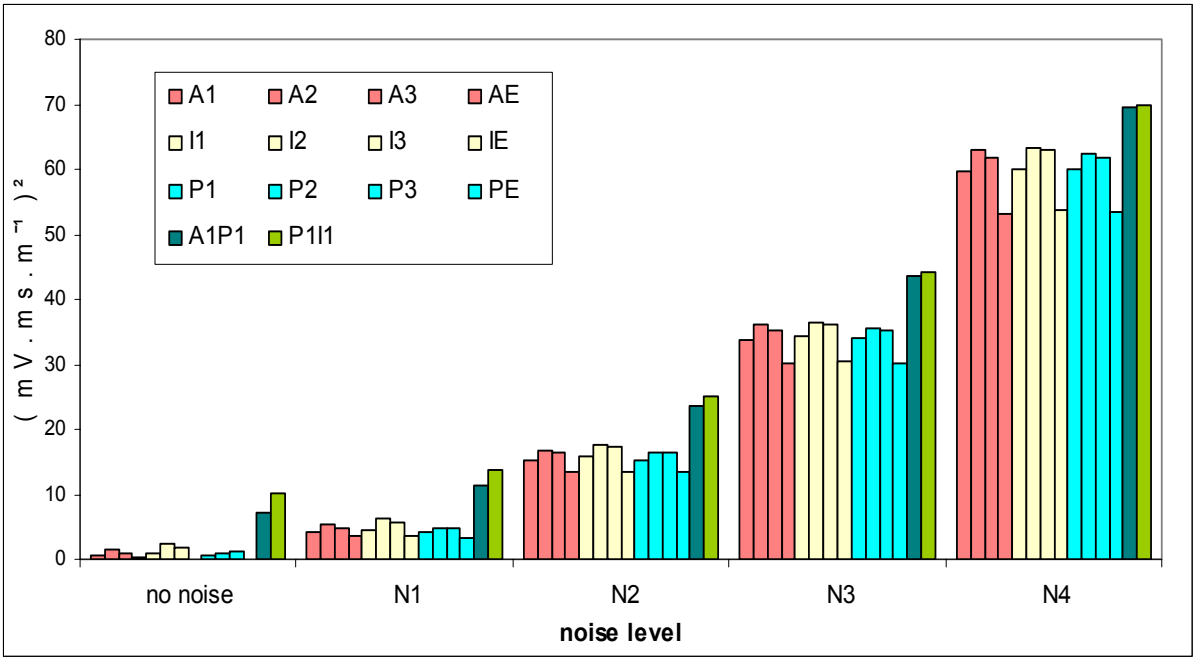

Fig. 2. MSG - mean square gradient of residual maps (as a measure of noise) for all positions and types of lesions and for different levels of noise. Lesion position: A–anterior, I–inferior, P–posterior, lesion types: E-epicardial, 1– small endocardial, 2– medium endocardial, 3– large transmural, A1P1 and P1I1 – multiple small endocardial lesions.

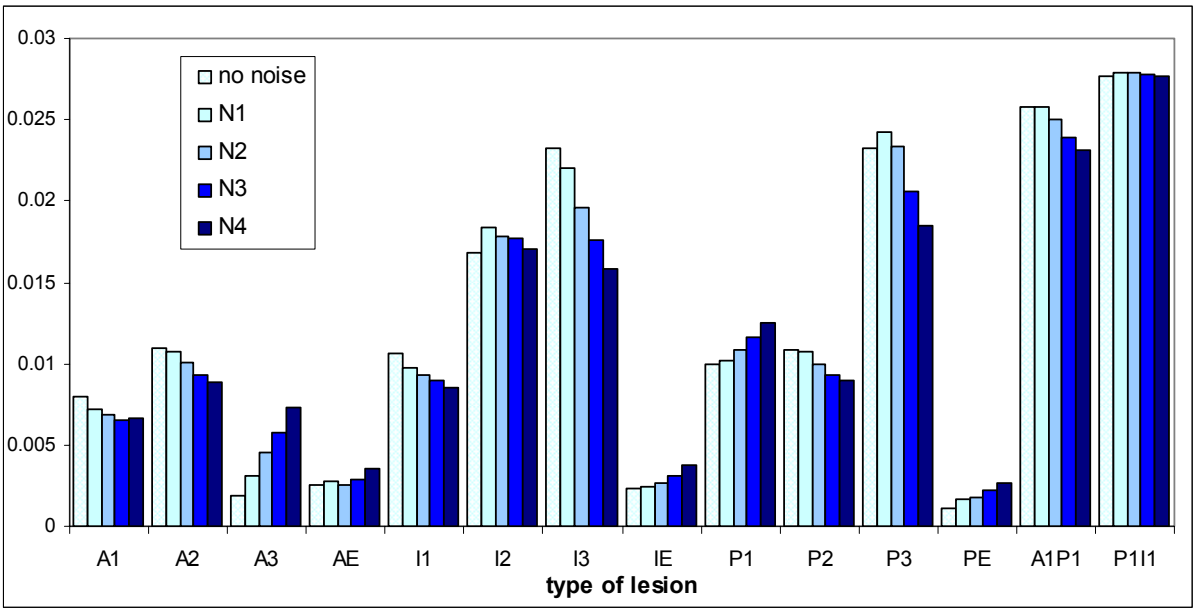

Fig. 3. QP parameter, averaged values for data without noise and with different levels of noise N1 – N4, for all positions and types of lesions. Lesion types and positions are the same as in Fig.1.

Value of QP parameter (Fig.3) was bigger for double lesions A1-P1, P1-I1 and for large transmural lesions I3 and P3 than for other small and medium endocardial and epicardial lesions. This behaviour did not hold for the large anterior transmural lesion A3 where also the value of R_{DQ}^2 was high. However, in general, value of QP did not significantly change with varied value of the noise in DI maps.

4. Discussion and Conclusion

Two criteria were proposed to estimate the credibility of the inverse solution when identifying local ischemic lesions: MSG criterion (2) and QP parameter (3).

Choice of the MSG criterion was based on the assumption that pattern of residual map is more fragmented when noise is present and differences between map values in neighbouring points are bigger. Significant differentiation between maps with various level of noise confirmed this expectation.

High value of QP should reveal large or multiple ischemic sources assuming that contribution of higher components of the multipole expansion of the real source (being still not random) was smaller than that of the random noise. Another presumption to use the QP parameter was that large ischemic region should be represented mostly by dipole and quadrupole while higher components of the multipole expansion can be neglected. However, small value of QP parameter resulting from high values of R_D^2 and also R_{DQ}^2 indicates that the field generated by transmural A3 ischemic region was not sufficiently approximated even by equivalent dipole plus quadrupole and probably also higher multipolar components were needed (Fig.4). Despite that, simulated DI maps of multiple lesions were clearly distinguished from small single lesions by the QP parameter.

To sum up, the mean square gradient of residual maps (MSG) exhibited low sensitivity to the size or complexity of the lesion and seems to give a good estimate of the noise in the input data. The QP parameter was suggested to detect events where the use of the method might be inappropriate, namely cases of large or multiple ischemic lesions in the myocardium.

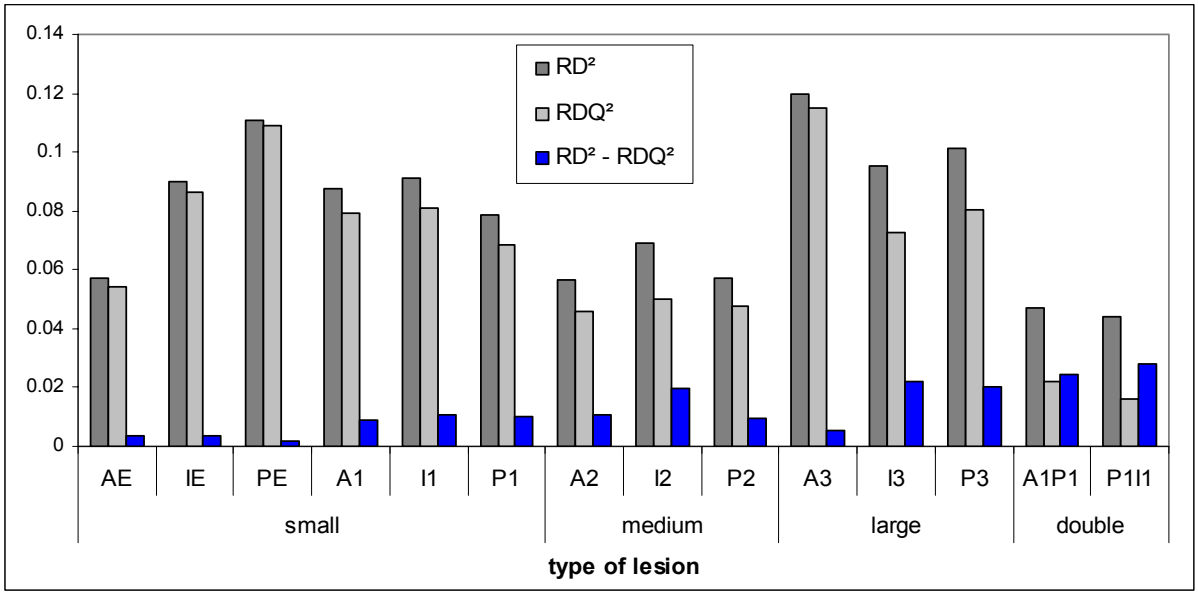

Fig. 4. Average of RD2 and RDQ2 and their difference - QP parameter for lesions of different types and sizes.

On simulated data, the applied criteria were helpful in distinguishing between cases of large or multiple regions of changed repolarization properties and cases with high level of random disturbances in DI maps. However, it was important to consider both parameters with respect to each other. Ability of the inverse method for diagnostic interpretation of body surface potential maps based on dipolar source model and benefit of the parameters proposed in this study should be further verified on real measurements.

Acknowledgements

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

References

[1] Szathmáry V., Osvald R.: 'An interactive computer model of propagated activation with analytically defined geometry of ventricles', Comput. Biomed. Res., 1998, 27, pp.27-38

[2] Tyšler M., Turzová M., Švehlíková J., Hebláková E., Filipová S.: Noninvasive detection of ischemic regions in the heart. IFMBE Proceedings, vol. 11, 2005, 2933-2937.

[3] Tiňová M., Tyšler M., Turzová M., Švehlíková J.: Inverse localization of preexcitation sites using "Jumping dipole". In: Electrocardiology '97, Proceedings of the XXVth international congress on electrocardiology. Eds.: Bacharova l., Macfarlane P.W., Singapore, New Jersey, London, Hong Kong, World Scientific, 1998.