# Comparison of Several ECG Intervals Used for Identification of Ischemic Lesions Based on Difference Integral Maps

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***Abstract.*** *Repolarization changes in small areas of myocardium can be detected from difference integral maps computed from body surface potentials measured on the same subject in situations with and without manifestation of ischemia. Detection was made by inverse solution with 2 dipoles. On 10 patients and 3 healthy subjects surface potentials were recorded at rest and during stress. Difference integral maps for 4 intervals of integration (QRST, QRSU, STT and STU) of electrocardiographic signal were computed and their properties and applicability as input data for inverse identification of ischemic lesions were compared. The results showed that better (more reliable) inverse solutions can be obtained from difference integral maps computed either from QRST or from STT interval of integration. The average correlation between such maps is 97%. The use of the end of U wave instead of the end of T wave didn't improve the results.*

*Keywords: Integral body surface potential maps, Ischemic lesions, Inverse solution to 2 dipoles*

## 1. Introduction

Myocardial ischemia is accompanied by changed shape of the repolarization phase of action potentials (AP) of myocytes in the ischemic area. Previously we reported a method for identification of local ischemic lesions by computing an inverse solution with two dipoles using difference integral maps (DIMs) of the QRST interval [1]. DIMs were computed by subtraction of QRST integral maps obtained under normal conditions from QRST integral maps obtained in situations with manifestation of ischemia.

Use of the whole QRST that represents both, depolarization and repolarization of the myocardium was based on the assumption that ischemic changes could affect also depolarization phase of myocytes AP by reduced AP amplitude and rate of rise [2]. The other possibility would be to evaluate only the STT interval in electrocardiogram (ECG) reflecting only repolarization phase of the myocardium.

Another issue when selecting the ECG interval for evaluation of repolarization changes is determination of the end of the repolarization. In many real signals small U wave appears after the T wave in ECG. According to some studies [3] T and U waves together represent the repolarization period. In such a case inclusion of U wave into the evaluated interval would be desirable.

In presented study the differences between DIMs computed from QRST and STT intervals of measured data were analyzed and obtained results of identification of small ischemic lesions were compared. Also influence of inclusion of U wave into the evaluated interval representing the myocardium repolarization was investigated.

## 2. Methods and Material

To reveal ischemic lesions with changed repolarization body surface potential maps from the same person recorded in situations with and without manifestation of possible ischemia were measured and used to compute DIMs. Integration intervals QT, QU, STT and STU including the myocardium repolarization phase were alternatively used in the computation supposing that these intervals include information on the changed repolarization. Equivalent cardiac generator with two dipoles was computed from the DIMs by an inverse solution. To find the best pair of dipoles, inverse solution was calculated for all pairs of dipoles located in predefined points evenly distributed within the modeled ventricular myocardium and minimum of rms difference (RMSDIF) between the original DIM and the DIM generated by the inversely estimated pair of dipoles was used. Not only dipoles from the best result but dipoles from all results with RMSDIF within 1% difference from the best solution were analyzed. Modified K-means clustering method was applied on all analyzed dipoles to divide them into 2 clusters [4]. If the dipoles from one dipole pair represented different ischemic lesions, it should be possible to assign them to different clusters. Any pair for which this procedure was not successful was excluded from the evaluation. The final gravity center of each cluster was then calculated and the mean dipole moment computed from all dipoles in the cluster was used to represent the lesion. The number of excluded pairs and mutual distance of cluster centers were used as the criteria to decide whether these clusters represent two separate lesions or only one lesion (i.e. the type of the lesion).

Body surface potential maps of 10 patients (p1-p10) with coronary artery disease and 3 healthy subjects (h1-h3) were computed from 64 ECG leads measured at rest and during an exercise test on supine ergometer at the load of 75 W. Fiducial points Q, S, T and U in averaged ECG signals were determined manually by visual observation of the computed rms signal from all measured leads in each time instant (Fig.1). Then, for each patient, integral maps for the time intervals QT, QU, STT and STU were computed at rest and during exercise. To subtract the integral maps measured at rest and during stress correctly, changes of heart rate were compensated by recalculation of the time integral values to the same interval length. DIMs for these intervals were then used as input data for the inverse procedure. The differences between the data obtained using the four time intervals and their influence on the results of the inverse solution were studied.

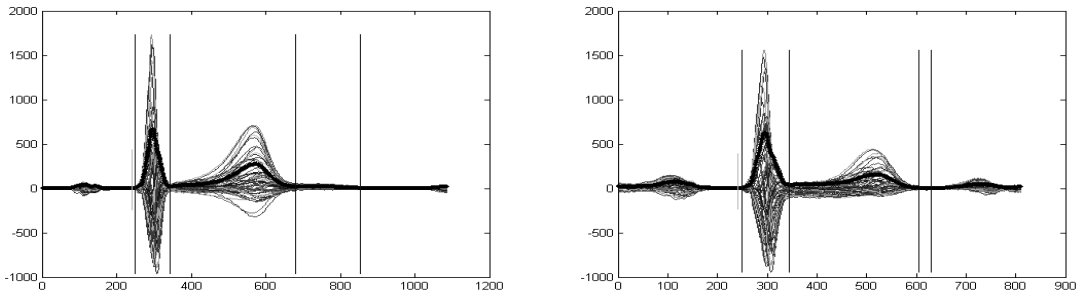


Fig.1. Averaged signals from 64 leads measured on patient p3 at rest (left) and during exercise (right). Black thick line represents rms value of signals. Vertical lines represent estimated fiducial points, from left to right: Q, S, T, U.

## 3. Results

To study properties of QRST, QRS and STT intervals of integration QRS integral maps were computed for all measured subjects at rest and during the stress. Also DIMs for QRST and

STT intervals of integration were computed. The correlation coefficients between the maps and their rms signals were evaluated.

The correlation of QRS integral maps at rest and at stress was 93-99%, average 97%. RMS values of maps at stress differed from the RMS values of maps at rest from 0% (p6) to 25% (p1), average 10%. Analogically, evaluation of DIMs showed that the correlation between DIMs computed for QRST and STT intervals of integration was high (94–100%, average 97%) except for patient p6 (55%). RMS values of maps differed from -1 to 26 %, average 14%.

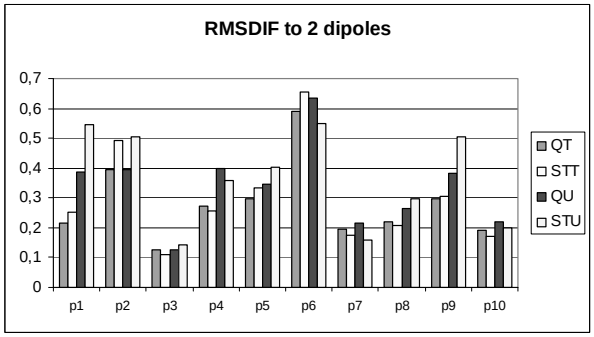


Fig.2. Relative rms differences (RMSDIF) between original DIMs and maps generated by the inversely estimated pairs of dipoles computed in all 10 patients.

To study the influence of U wave inclusion in each patient data DIMs were computed for 4 possible intervals of integration: QT, QU, STT and STU and the differences in inverse solutions with 2 dipoles were observed. The main observed feature of the inverse solution was always the value of the RMSDIF difference between the original DIM and the map generated by the inversely estimated dipole or pair of dipoles (Fig. 2). This value carries information on dipolarity of the input DIM and applicability of the inverse solution for each particular case. According to the RMSDIF values from inverse solutions to 2 dipoles patients were divided into 2 groups. Patients with similar values of RMSDIF regardless the interval of integration (p2, p3, p7, p10) were assigned to the first group. Patient p6 was excluded from further examination because neither 1 dipole nor 2 dipoles could satisfactorily represent his DIM (RMSDIF was 65% or 59% resp.). Rest of patients was assigned to the second group.

In the first group of patients following selected features of inverse solution characterizing the type of the lesion were similar regardless the interval of integration (Fig.3): no excluded pairs from clustering method and a large mutual distance between cluster centers characterizing two simultaneous lesions (p3, p7); small mutual distance determining 1 lesion (p2); large number of excluded pairs and also a large number of solutions indicating that DIM does not represent neither 1 nor 2 small local lesions (p10).

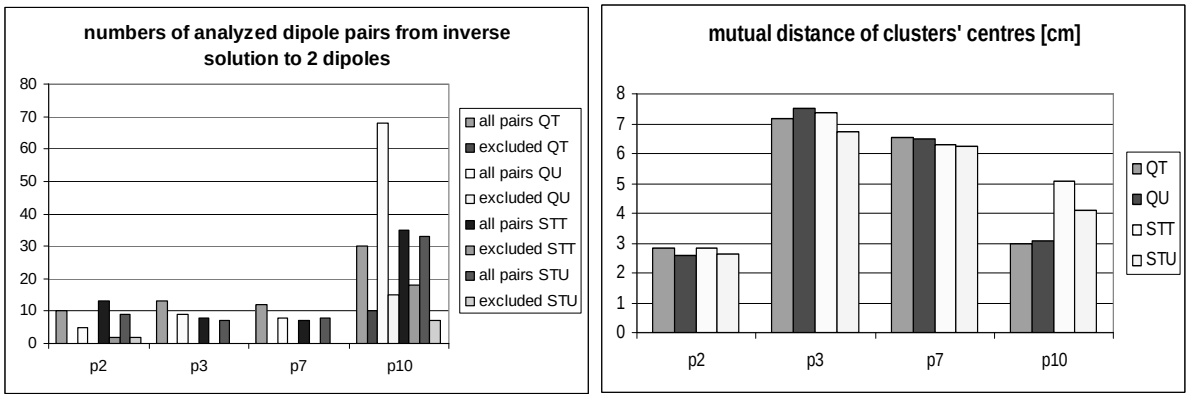


Fig.3. Properties of inverse solutions to 2 dipoles for the first group of patients. Left: The numbers of all pairs of dipoles used in the clustering method and the numbers of pairs that could not be divided uniquely to different clusters. Right: Mutual distance of inversely determined centers of clusters for 4 intervals of integration.

In the second group of patients the RMSDIF for DIMs computed from intervals defined by the end of U wave were greater than for DIMs computed using the end of T wave. Therefore we decided to consider the QT and STT intervals to be more reliable. Further evaluations were done on these 2 intervals.

The nonzero number of excluded pairs together with a large standard deviation of positions of dipoles in the clusters (Fig.4) indicated that these results didn't represent a local lesion but most probably large ischemic areas.

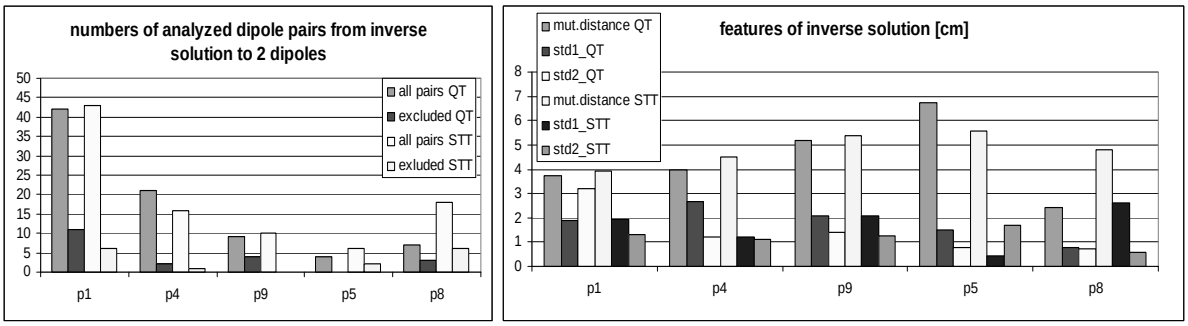


Fig.4. Properties of inverse solutions to 2 dipoles for the second group of patients for QRST and STT intervals of integration. Left: The numbers of all pairs of dipoles used in the clustering method and the numbers of pairs that could not be divided uniquely to different clusters. Right: Mutual distance of inversely determined centers of clusters and standard deviations of positions of dipoles in each cluster.

## 4. Discussion and Conclusions

Although it is assumed that U wave represents late repolarization activities of myocytes, the presented study indicates that the substantial information on repolarization changes for our inverse method is included in the QRST or STT intervals. The results for 13 measured subjects showed that DIMs computed from QRST or STT interval of integration are in very good correlation (97%). The properties of inverse solutions to 2 dipoles for identification of local ischemic lesions computed either from QRST or from STT interval of integration are comparable and give similar results.

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