Clinical use of body surface potential mapping in cardiac arrhythmias

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ABSTRACT

The electrocardiology and specifically body surface potential maps (BSPM) have two main objectives in the arrhythmologic field: 1) identification of signs of susceptibility to arrhythmias, and 2) identification of site of origin of the arrhythmias. In order to detect the susceptibility to ventricular arrhythmias, maps were recorded with different lead systems by different authors and, in particular, various methods of analysis of BSPM have been used to study repolarization potentials: QRST integral maps, eigenvector analysis, principal component analysis, autocorrelation analysis. From these analyses several markers of vulnerability to arrhythmias were identified, which demonstrated a predictive accuracy of various degree in selected patient populations. As concerns the identification of site of origin of the arrhythmias, the use of 62 leads BSPMs during endocardial pace mapping technique enabled more precise identification of the site of origin of postinfarction ventricular tachycardia episodes, compared with the use of the 12-lead electrocardiography (ECG). Recently a new electrocardiographic modality (ECG-imaging) enabled to compute non-invasively and with high resolution epicardial potential distribution and epicardial activation sequences from potentials recorded on the body surface together with cardiac computed tomography images. The ECG-imaging has been successfully applied in humans using geometrical information from computed tomography of each subject, in different heart conditions: normal heart, heart with a conduction disorder, focal activation initiated by right or left ventricular pacing, focal ventricular tachycardia and atrial flutter. *(Anadolu Kardiyol Derg 2007: 7 Suppl 1; 8-10)*

Key words: body surface potential mapping, arrhythmias, electrocardiography

Introduction

The electrocardiographic techniques still today have a primary role in the field of arrhythmias diagnosis, in which no other imaging techniques can provide relevant insights.

In the arrhythmologic field the electrocardiology in general and specifically body surface potential mapping have two main objectives: 1) identification of signs of susceptibility to arrhythmias, and 2) identification of site of origin of the arrhythmias.

The most general advantage of body surface potential maps (BSPM) is the fact that they record cardiac potentials from broad areas of the chest, thus enabling the detection of significant physiologic and possibly diagnostic information outside the precordial regions usually explored. Moreover, BSPMs provide the spatial as well as the temporal and amplitude components of cardiac electrical activity, whereas the ECG scalar waveforms only present the voltage variation with time in a given site.

Body surface potential maps have two major advantages over the conventional 12-lead electrocardiogram (ECG): 1) to explore the entire chest surface, thus providing all the information on the cardiac electric field available at the body surface; 2) to be more sensitive in detecting local electrical events, such as local conduction disturbances or regional heterogeneities of ventricular recovery.

Susceptibility to ventricular arrhythmias

Cardiac arrhythmias are produced through a variety of mechanisms that may be favoured by a wide range of myocardial conditions expressing themselves electrocardiographic changes. Thus, electrocardiographic signs predictive of arrhythmias could be expected to be a number of specific, but non-selective markers, each possibly identifying a different arrhythmogenic substrate.

Many investigations have focused on the key role of ventricular repolarization abnormalities in the genesis of cardiac arrhythmias. The vulnerability to arrhythmias can arise from a state of heterogeneity of repolarization, i.e. an abnormal dispersion of recovery times, which can be detected by analysing even a single beat, using the 12-lead ECG or multiple thoracic leads i.e. BSPM. Maps can be recorded with different lead system and various methods of analysis of BSPM have been used to study repolarization potentials.

QRST integral maps

Areas of QRST deflections mainly reflect the intrinsic repolarization properties and are largely independent of ventricular excitation sequence. A complex, multipolar pattern has been related, on the basis of experimental observations, to local heterogeneities of the ventricular recovery process and thus to cardiac states of vulnerability to arrhythmias (1). However, a

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clear multipolar pattern, which most likely reflects gross regional inequalities of repolarization, was reported only in small percentages of patients affected by ventricular arrhythmias. On the other hand, "multipolarity" can only be detected on maps, not on standard ECG.

Eigenvector analysis

Eigenvector analysis (2) was proposed as a method to detect and quantify the non-dipolar components not evident on visual inspection of the integral maps. The cumulative contribution of the eigenvectors beyond the 3rd to an individual map, expressed as percentage contribution of the total map content, has been considered a "non-dipolar content" of that map.

Eigenvector analysis was applied to QRST integral maps of 2 groups of patients with old myocardial infarction (11 patients with episodes of sustained ventricular tachycardia and 62 without arrhythmias) and in a control group of healthy subjects (3). On average, the non-dipolar content was significantly greater in patients with MI than in controls (8.3±6.4% vs 4.1±2.2%, $p<0.001$) and, among patients, in those with ventricular tachycardia (7.2±5.3% vs 16.6±8.5%, $p<0.001$). These findings were in agreement with those reported by Abildskov et al. (4). Thus, the high non-dipolar content of QRST maps in patients with ventricular tachycardia suggests the presence of local disparities of repolarization and it may be considered a useful marker of susceptibility to malignant arrhythmias.

Hubley-Kozey et al. (5) derived 16 eigenvectors from the total set of 204 QRST maps (102 patients with ventricular tachyarrhythmias and 102 patients without), but did not find a statistically significant difference in dipolar content between the two groups (13.1±9.7% vs 12.9±10.2%, $p>0.05$). Because the nondipolar content did not perform well in their study population, the authors examined how individual eigenvector pattern contributes to QRST integral maps in each group of patients. Statistically significant differences were found between the values of Karhunen-Loeve coefficients in ventricular tachycardia (VT) and non-VT groups for the 6th, 4th, 13th, 5th, 1st, 2nd, and 11th eigenvectors, in order of significance levels. Using stepwise discriminant analysis, they selected features subsets that best discriminated between the two groups. For an optimal set of 8 spatial features, the sensitivity and specificity of the classifier for detecting patients with VT in 1000 test sets were 90±4% and 78±6%, respectively. The authors concluded that the multiple body-surface ECGs contain valuable spatial features that can identify the presence of an arrhythmogenic substrate in the myocardium of patients at risk for ventricular arrhythmias.

Eigenvector analysis was also applied to QRST and ST-T integral maps. We found that the percent contribution of non-dipolar eigenvectors (all eigenvectors beyond the third) to integral maps was significantly higher in LQTS patients than in normals (6). Moreover, 8 patients who presented a high non-dipolar content did not show a multipeak distribution on their integral maps. This demonstrates that eigenvector analysis can detect non-dipolar components not evident on visual inspection of the integral maps.

Principal Component Analysis

We applied principal component analysis (PCA) to all ST-T waves recorded on the thoracic surface. Principal component analysis allows the identification of one set of values, corresponding to the 1st principal component, which better represents most of the original sets of data recorded. Usually the first 3 components provide nearly the total variation of the original data. We proposed to compute the "Similarity Index" (ratio of first eigenvalue by the sum of all eigenvalues). The value of similarity index is inversely proportional to the variability of T wave morphologies and a low value is considered a marker of repolarization heterogeneity. In our experience, similarity index was found significantly lower than normal in patients affected by congenital LQTS (7), in patients with arrhythmogenic right ventricular dysplasia (ARVD) and VTs (8), and in patients with myocardial infarction.

Autocorrelation analysis

In order to analyze the instantaneous variations of repolarization potentials we proposed two indices: early repolarization deviation index (ERDI) and late repolarization deviation index (LRDI). Visually, the pattern of potential maps is generally constant during normal repolarization, apart from changes in amplitude. The ERDI and LRDI are numerical indices which describe deviations from this behaviour during repolarization, from the J point to the T peak and from the peak to the end of T wave, respectively (9, 10). Significant gender differences in ERDI and LRDI were found, which could partly account for the higher risk of developing arrhythmias, under QT prolonging conditions, of the females vs males (10). We computed these indices also in small series of patients with different cardiac diseases (ARVD, left ventricular hypertrophy due to aortic stenosis, myocardial infarction with and without arrhythmias) and in some groups significant differences from normal subjects were observed.

Identification of site of origin of ventricular tachycardias

Extensive investigations were made by Sippens-Groenewegen et al. to assess the value of BSPMs in localizing the site of origin of ectopic ventricular activation in patients with a structurally normal heart and with myocardial infarction (11-13). In patients with normal cardiac anatomy, the QRS maps allowed to discriminate among 38 different left ventricular and right ventricular segments of ectopic endocardial impulse formation (11). The use of 62 leads BSPMs instead of the 12-lead ECG during endocardial pace mapping technique enhanced the localization resolution of this technique and thus enabled more precise identification of the site of origin of postinfarction VT episodes (12). In patients with previous anterior and inferior myocardial infarction the same authors demonstrated that QRS integral maps enabled a precise localization of the origin of postinfarction VT in 62% and regional approximation (identification of a segment immediately adjacent to the actual endocardial segment of origin) in 30%of tachycardias (13).

A promise technique for localizing site of origin of arrhythmias is the "ECG-imaging" recently developed by Rudy and co-workers (14). This new electrocardiographic modality enables to compute non-invasively and with high resolution epicardial potential distribution and epicardial activation sequences from potentials recorded on the body surface together with cardiac computed tomography images.

The ECG-imaging has been successfully applied in humans (15, 16), using geometrical information from computed tomography of each subject, in different heart conditions: normal heart, heart with a conduction disorder (right bundle branch block), focal activation initiated by right or left ventricular pacing, and atrial flutter. Recently, ECG-imaging was used in clinical setting for arrhythmia diagnosis and management in a young

athlete with a small apical diverticulum of the left ventricle and unusual VT (17). The BSPM of a single premature ventricular complex showing a QRS morphology identical to the clinical VT and a chest computer tomography were used to generate epicardial activation sequence, which indicated the origin of premature ventricular complex at the site of the diverticulum. This finding was confirmed during electrophysiological study and by epicardial mapping through a subxiphoid puncture.

McClelland et al (18) applied to the body surface potentials an inverse solution, which adopts a general torso model in which the same anatomic data are used irrespective of the body habitus. Despite this limitation, they were able to reconstruct, in 5 patients during VT, epicardial isochronal maps indicating the exit site and the re-entry circuit of the tachycardia .

Conclusion

Electrocardiology has a primary role in the field of arrhythmias and conduction disturbances, in which no other technique can provide relevant insights. Specifically, BSPMs by exploring the entire chest surface give the possibility to detect significant physiologic and prognostic information. In particular the ECG-imaging, based on the solution of the "inverse problem", which is the final aim of electrocardiography, has been proved to accurately reconstruct epicardial activation map from which the site of origin of ventricular arrhythmias can be identified.

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