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Cardiac Micropotentials Reached From One Systole as Non-dipolar Residue by Singular Value Decomposition

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Summary

Cardiac micropotentials are considered to have a predictive value in critical ventricular tachycardia or sudden death. These micropotentials are obtained by numeric filtration of the result of sequential averaging of about 200 systoles (i.e. of measurement at about 3 min interval) which is significantly influenced by known intraindividual ECG variability. It follows from our previous studies that the non-dipolar residue (i.e. the sum of all components of an equivalent source of the heart electrical field with the exception of the first three dominant dipolar components) corresponds by its nature to the cardiac micropotentials, i.e. to late potentials. Verification of this hypothesis utilizing singular value decomposition and replacing the sequential averaging by "surface" averaging of the matrix of synchronously measured ECGs is the aim of this project. The results of the present study can be considered as a confirmation of this hypothesis. These results provide a better understanding of the structure of the body surface potential distribution and for clinical purposes they make it possible to attain cardiac micropotentials (late potentials) from one systole.

Key words

Cardiac electrical field – Body surface potential distribution – Late potentials – Non-dipolar residue – Orthogonal transformation

Introduction

The significance of orthogonal transformations for the body surface potential distribution (BSPD) processing is well known. From the beginning of the 1960s, they have been utilized for surface ECG matrix processing. Starting by factor analysis and principal factors (Scher et al. 1960, Horan *et al.* 1964), many papers based on the multipole concept have been published (Yeh and Martinek 1958, Geselowitz 1963, Brody 1968, Titomir 1980), Fourrier transformation (Kneppo 1976), Karhunen-Loevy transformation (Halliday *et al.* 1973, Lux *et al.* 1986, Evans *et al.* 1981, Uijen *et al.* 1984), and also singular value decomposition (Damen and van der Kam 1982, Tanaka *et al.* 1986) have been used.

Individual components of these transformations can be interpreted as the components of an equivalent source of the the heart electrical field in n-dimensional space. For example they can be maintained within the framework of the multipole concept as components of a dipole, quadrupole, octupole, etc.

The validity of the superposition of the heart electrical field has been demonstrated by these studies, i.e. it has been proved that every surface ECG can be reconstructed by linear combination of orthogonal (uncorrelated) ECGs.

Orthogonal transformations exhibit some important properties. As has just been mentioned, every surface ECG can be reconstructed at the level of the signal/noise ratio from a relative and quantitatively equal set of "virtual" ECGs (i.e. ECGs from n-dimensional space). For example, Horan *et al.* 1964) found a set of 15 these ECGs as sufficient for this level of precision of surface ECGs reconstruction.

The next important property of orthogonal procedures is the rapidly decreasing rate of individual components on the resultant reconstructed signal amplitude. For example, the contribution of the first component is about 35 %, the contribution of the first two components is about 65 % and the contribution of the first three components is about 85 % of the whole signal. This fact makes it possible to choose the minimum subset necessary for acquiring the level of signal reconstruction (all other components being considered as components of the noise).

An inverse relationship is known for the frequency spectrum of individual components – the frequency spectrum of individual components increases with the number of components in a given set sequence. This fact makes it possible to obtain the required resulting spectrum without standard filtration, which might be a source of significant output signal

distortions. Moreover, this procedure enables to obtain the surface distribution of these micropotentials and to study their topographic properties.

An important property of orthogonal transformations appears to be the constant size of the component sets. A small and constant number of components permits the adoption of standard statistical procedures and methods employed in the field of neuronal networks for BSPD data processing. At the present time, these transformations also represent useful procedure for data managing, i.e. data reduction (BSPD data of one subject is about 0.4 MB).

In previous papers (Drška 1986, Drška *et al.* 1988, 1990, 1991) a procedure for non-dipolar residue extraction as RMS (root mean squares) of residual potential differences between measured ECGs and ECGs reconstructed from VCG orthogonal ECGs was described. It is obvious that according to this concept, the dominant dipolar component of equivalent source is represented by the VCG signal.

It follows from this that the non-dipolar residue can be obtained as residual potential differences between a measured ECG signal and a reconstructed one from the dipolar component of an equivalent source of the electrical field of the heart using the method of least squares. In other words, this residue corresponds to the sum of all other components of the equivalent source with the exception of the dominant dipolar component. Peak values of the residue are about 100 μV RMS.

The significance of the non-dipolar residue is evident: this residue represents that part of the electrocardiological signal which can be obtained only by BSPD processing, not by vectorcardiography describing predominantly the dipolar component of equivalent source.

Methods

This study is based on the verification of the working hypothesis that non-dipolar residue corresponds by its nature to the cardiac micropotentials and then to the late potential. Moreover, the proposed method is based on the utilization of one of the mentioned properties of orthogonal transformations, i.e. on the decreasing frequency spectrum of individual components and on the possibility of separating the chosen subsets of these components.

The input data consisted of a matrix of 80 ECGs synchronously recorded and preprocessed by the multichannel system CARDIAG 128.2 developed and made by ZPA Čakovice (Czech Republic).

In this study the singular value decomposition was used for data processing. The non-dipolar residue was then determined as follows:

a) as the RMS of differences between values of signal resynthesized from the first twenty orthogonal components and values of the output signal synthesized from the first three orthogonal components;

b) as the RMS of resultant values of resynthesis from the 4th to the Kth SVD component, where K=20 (i.e. first three components being excluded).

Singular value decomposition was adopted for its capability to provide several output parameters:

1. n-dimensional set of orthogonal functions on a unit amplitude scale (Fig. 1);

2. a vector of singular values;

3. n-dimensional set of coefficients for input ECG signal reconstruction.

From the orthogonal functions and corresponding singular values of orthogonal components (or "virtual" orthogonal ECGs) the n-dimensional set was calculated having real amplitudes.

In the next step, the reconstruction of surface ECG signals created by K_0th to Kth orthogonal components (where K_0 = 4 to 8) was performed using the appropriate subset of orthogonal components and coefficients for input signal reconstruction. The data obtained in this way were then interpreted as a non-dipolar residue surface distribution.

After this, these values from all surface lead points were averaged and processed as RMS. The described procedure can be characterized as surface averaging in contrast to the usual sequential averaging of the time series of ECGs which have a place in the standard method of micropotentials extraction.

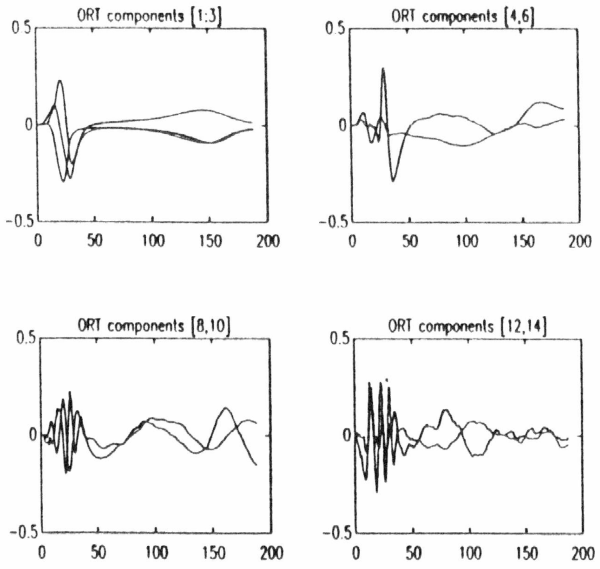

Fig. 1
Orthogonal functions: the result of singular value decomposition of a matrix of 80 surface ECGs. Numbers in the figure heading represent the order of individual components. The uniform amplitude of orthogonal components and their increasing frequency spectrum is evident.

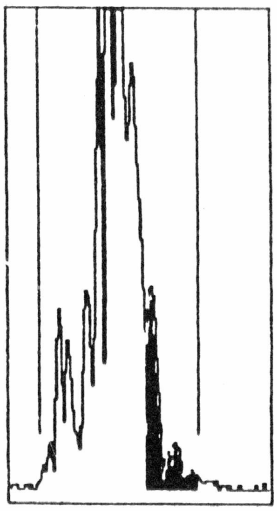

Fig. 2
Output protocol of the standard method of late potential extraction with the Simpson's criteria of micropotentials evaluation. "Total QRS" means the QRS duration including micropotentials at the end of the QRS interval, "Under 40 μV" means the time interval within which the amplitude was lower than 40 μV. "Last 40 ms" means the RMS of the signal within the last 40 ms of QRS interval.

Results

The resulting data correspond, by their nature and properties, to the definition of cardiac micropotentials. This hypothesis is confirmed by the results of experiments when these data were processed by analogous filtration as was proposed for standard extraction of micropotentials (Fig. 2).

The described method of surface ECG matrix processing using the singular value decomposition led to analogous results as the method of non-dipolar residue extraction developed earlier (Drška 1986, Drška *et al.* 1988, 1990). The relationship of the non-dipolar residue and several pathophysiological categories (regional wall motion abnormality and the size of old myocardial infarction area) has been confirmed (Drška *et al.* 1988, 1990).

Discussion

The described procedure enables to obtain the appropriate frequency spectrum of the resulting signal, and to utilize only a selected subset of orthogonal components for studying the surface distribution of a signal created by this subset of orthogonal components (Fig. 3).

This procedure can be considered as an analogy of the procedure of micropotential extraction which is based on sequential averaging of long series of ECGs. It is being proposed to adopt an averaging procedure for of values derived from synchronous recordings of 80 surface ECGs of a single systole.

The standard method of micropotential extraction requires a special system permitting the measurement and averaging of about 200 systoles representing the result of about 3 min period. The input data are significantly affected by intraindividual variability of the electrical systole and by the effects of respiration. Micropotential extraction is impeded for example, by atrial fibrillations.

The proposed procedure makes it possible to eliminate these factors and, moreover, to create conditions for obtaining data, for example, from extrasystoles. In this case, the occurrence of symptoms that predict malignant arrhythmias, the existence of which can not be proved during a "normal" systole, can be expected.

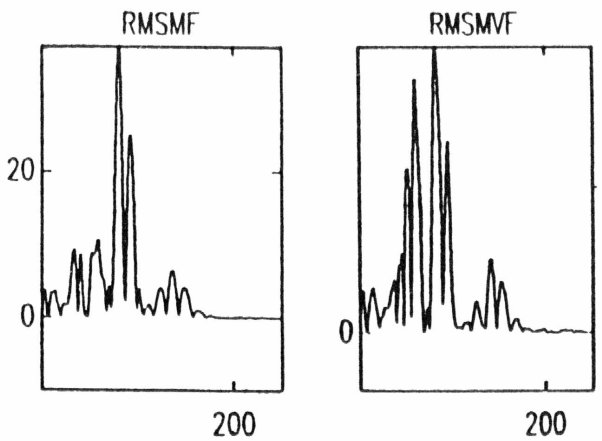

Fig. 3
Cardiac micropotentials obtained by the matrix of 80 ECGs synchronously measured from the chest surface and processed using the singular value decomposition. For better comparison with the late potentials, these data were processed by analogous digital filtration (Butterworth bidirectional filter – 40 and 250 Hz). Scale on the ordinate is given in 100 μV, scale on the abscissa is given in ms. RMSMF – curve (left) represents output data from the 4th to 20th singular value decomposition components.

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Reprint Requests

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