Dynamic beat-to-beat changes of the cardiac electric field due to psycho-emotional load

Dynamické zmeny elektrického poľa srdca od úderu k úderu, vyvolané psycho-emocionálnou záťažou

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Abstract. The aim of the study was to analyze the up-to-now unexplored beat-to-beat dynamism of the previously described reactive changes in ventricular repolarization, due to sympathetic activation in a psycho-emotional stress situation. R-R intervals, selected parameters of depolarization and repolarization integral body surface potential maps (BSPMs) and blood pressure were evaluated in sitting subjects at rest and during the mental arithmetic test. Despite negligible effects on depolarization, the cognitive stress induced significant dynamic changes of the main repolarization parameters. The amplitudes of the integral ST and QRST BSPMs and the ST non-dipolarity index (NDI(ST)) significantly decreased and α-angle between the QRS and ST eigenvectors significantly rose. These reactive changes were gradual, began with a short latency, reaching their maximum after 30-60 seconds. The character of these dynamic BSPMs changes corresponds to the pattern of the complex sympathergic cardiovascular response to mental tasks. Fig. 3, Ref. 36, Online full text (Free, PDF) www.cardiology.sk

Key words: integral body surface potential maps ECG – ventricular repolarization – beat-to-beat dynamism – reactive changes – psycho-emotional stress

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Abstrakt. Cieľom práce bolo analyzovať od úderu srdca k úderu, dynamiku reaktívnych zmien komorovej repolarizácie, vyvolaných aktiváciou sympatika v priebehu psycho-emocionálnej záťaže. Hodnotili sme R-R intervaly, vybrané parametre integrálových povrchových potenciálových máp depolarizácie a repolarizácie (BSPMs) a krvný tlak, posediačky v pokoji a počas testu mentálnej aritmetiky. Stresová situácia vyvolaná kognitívnou záťažou sa prejaví signifikantnými zmenami hlavných repolarizačných parametrov – poklesom amplitúd ST a QRST BSPMs a indexu non-dipolarity ST (NDI(ST)) a nárastom α-uhla medzi QRS and ST vektormi, pričom priebeh depolarizácie sa nemení. Tieto postupné reaktívne zmeny nastupujú po krátkej latencii a za 36 – 60 sekúnd dosahujú maxima. Charakter týchto dynamických zmien BSPMs je v súlade s priebehom komplexnej sympatergnej odpovede kardiovaskulárneho systému na mentálnu záťaž. Obr. 3, Lit. 36, Online full text (Free, PDF) www.cardiology.sk

Kľúčové slová: integrálne povrchové mapy EKG – komorová repolarizácia – dynamika od úderu srdca k úderu – reaktívne zmeny – psycho-emocionálny stres

Electrophysiological parameters characterizing ventricular repolarization have been found to be sensitive indicators which reflect the direct effect of sympathetic activation on the ventricular myocardium. Numerous experimental studies have demonstrated that minimal local changes of the myocardial action potential pattern can significantly alter

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the amplitude, duration and polarity of the T wave, with negligible, if any, changes in the QRS complex (1). In earlier studies the pattern of ventricular repolarization was assessed by changes in T-wave shape and amplitude (2, 3). To enable the quantitative evaluation, the maximal spatial T-vector was proposed by Ruttkay-Nedecký (4) as a convenient parameter. To gain more detailed information on the time and space-related electrophysiological processes in the heart, attention has been devoted to the study of the information content of the integral body surface potential maps (BSPMs). They are still an important source of information in the electrocardiographic research of autonomic nervous system control of cardiac function. Several papers offer basic data on the pattern of ventricular depolarization and repolarization time-integral BSPMs in clinically normal subjects at rest (5 – 11). However, in subjects with no cardiovascular symptomatology, only a few studies have dealt so far with the problem of variability in the pattern of BSPMs or with reactive changes due to different physiological conditions, involving variations in the autonomic drive of ventricles (6, 9 – 15). There is a cogent limitation in interpreting these studies, as mainly a single BSPM from one, randomly selected heartbeat (technical limits of the equipment), or averages from a short sequence of several maps, were used to evaluate the significance of their changes in time, or in different situations. Reliable testing of cardiovascular reactivity to somatic or psycho-emotional tasks, involves continual monitoring of investigated parameters during the anticipation of, administration of, and recovery from stimuli or tasks. Computer based BSPMs recording enabled a beat-to-beat analysis of the dynamic behavior of the cardiac electric field (16). Using this methodology, we evidenced spontaneous, non-random, respiratory and low frequency oscillations of the ventricular repolarization pattern, and analyzed the course of body posture associated changes in ventricular recovery in our previous study (17).

The aim of the present study was a beat-to-beat description of the dynamic reactive changes of various parameters of the BSPMs in a sympathergic situation, brought about by mental arithmetic (MA) – a consistent cognitive test which involves increased alertness with intellectual and emotional strain.

Subjects and Methods

A group of 9 healthy men, median age 29 years, disposed to the integrated cardiovascular response to psycho-emotional stress (out of a preliminary tested 13 subjects), was studied. None of them was obese, smoked or was taking any medication.

Study protocol

Each subject, naturally breathing, had continuous BSPM recordings in the following situations: 30 s in seated position at rest, 120 s during a mental arithmetic test – controlled quick repetitive subtraction of a two-digit number from a four-digit one (MA), and 120 s of recovery after the test.

Data recording and processing

Using a layout of 64 torso electrodes, unipolar ECG records were obtained by the BioSemi Mark-8 System (Netherlands). Adhesive one-use electrodes were used, to prevent their incidental displacement. After a linear base-line adjustment of the measured 64 ECG signals, by a transfer matrix, ECG signals were estimated in another 128 chest locations. From the resultant data set the depolarization QRS, repolarization ST and QRST integral BSPMs for each heartbeat were constructed in 192 points of a regular grid (16 columns x 12 rows), representing the human chest surface. The following parameters were beat-to-beat evaluated: R-R intervals (RR), the values and localizations of maxima and minima of the respective integral BSPMs, their peak-to-trough amplitudes (QRSampl, STampl, QRSTampl), as well as computed parameters – the angle α between the QRS and QRST eigenvectors and the non-dipolarity indices (NDI). For details on data recording and processing see (8, 17).

The semi-automatic oscillometric method (Omron 705 IT) was used to measure the blood pressure (BP) repetitively in each experimental situation. As an estimate of the left ventricular performance the rate-pressure product (RPP), i.e. the product of simultaneous heart rate (HR) and systolic BP values, was calculated.

The human research and ethical committee of the Institute of Normal and Pathological Physiology SAS approved the design of this study.

Statistical analysis

Throughout the study, comparison of all numerical data within the situations, intra-individually or in the group, was performed by the two-tailed Student's t-test and F-test. Discrete Fourier Transform in the frequency domain from 2.4 to 28 $c.min^{-1}$ was used to detect the possible periodicity hidden in the variability of the BSPM parameters. The minimal level of significance was set to $P < 0.05$

Results

In individual subjects, depending on their HR 335 – 426 time, integral BSPMs were evaluated. The pattern of all maps was dipolar, with positivity over the left precordium, negative values over the right anterior torso in QRS BSPMs and right posterior torso in ST and QRST BSPMs, but it varied spontaneously in basal resting conditions, as well as in the reactive states. The greatest within-subject standard deviations were found in the precordial region of positive potentials, dominating in repolarization ST maps and contributing thereby also to the variability of the QRST BSPMs.

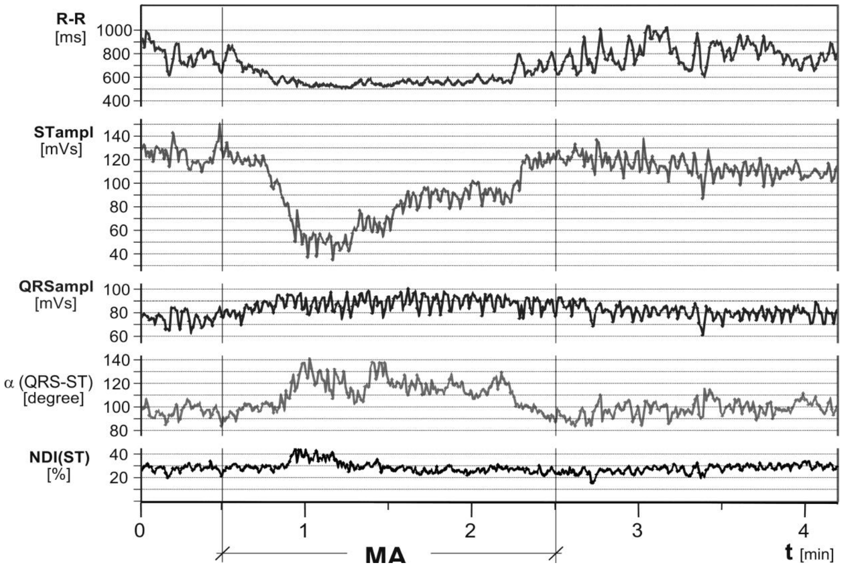

Figure 1 Representative continual beat-to-beat recording of RR and of the amplitudes of the integral ST and QRS BSPMs, α-angle between the QRS and ST eigenvectors and NDI (ST) the non-dipolarity index, from one subject, before, during and after the mental arithmetic test (MA).

In the continual follow-up, the pattern of BSPMs clearly oscillates from beat-to-beat. As evident from the representative recordings of – RR intervals, selected integral BSPM parameters characterizing the ventricular depolarization (QRSampl) and myocardial recovery processes (STampl), non-dipolarity index (NDI) and the angle (**α**) between the QRS and ST eigenvectors **(Figure 1**) – there are several nonrandom components of the considerable variability of the investigated parameters. Two significant, clearly separated periodic oscillations – in the low (0.05 – 0.12 Hz) (LF) and high (0.28 – 0.37 Hz) (HF) frequency band were identified, dominant in the repolarization.

The representative record **(Figure 1)** as well the group--mean values of the main BSPM parameters **(Figure 2**), document the dynamic pattern and proportions of the reactive changes of depolarization (QRSampl) and repolarization (STampl and QRSTampl) BSPMs. The MA stress induced reactions **(Figure 1** and **Figure 2)** began in all subjects with a short latency after initiation of the mental task, usually peaked significantly at 30 – 60 seconds, and returned to the control values at the end of the test, or some heart beats after. In the course of doing the arithmetic, at the peak of the reaction, there was on average a significant increase of heart rate to 131% (from 75 to 98 beats/min), of blood pressure to 116% resp. 110% (from 118/69 to 137/76 mmHg), and of the rate-pressure product (RPP) to 144% (from 8760 to 12650), of their respective control values at rest ($P<0.001$ for all changes).

Simultaneously in the main parameters of the integral repolarization BSPMs – the STampl fell to 82 % (from 141 to 116 μVs), and QRSTampl to 81% (from 154 to 126 μVs) (both $P<0.001$), while there was only a negligible, insignificant, rise in depolarization QRSampl. The NDI (ST) fell on average from 12.4% to 10.5% ($P<0.005$) and the angle α rose from 41.0° to 45.4° ($P<0.01$). The gradual reactive fall in MA QRSTampl, as well as its return to the resting values at the end of the test, opposed the course of the increasing rate-pressure product (RPP) **(Figure 3)**. The pattern of these responses was inter-individually conformable, but variable in magnitude.

Discussion

The presented qualitative and quantitative characteristics of depolarization and repolarization time-integral BSPMs at rest are concordant with previous reports for clinically normal males (5 – 11). Circulatory adaptations, involving autonomic control, constitute in daily life an essential part of the "spontaneous" intra-individual variability of these electrophysiological functions of the heart. Results of this study call attention to the emotional stress dependent beat-to-beat alteration of the cardiac electric field. This situation – provoking an integrated response of the cardiovascular system – deviates substantially in particular the repolarization BSPMs parameters, from their respective means at rest. The reactions are dynamic, with evident transition periods in reaching new levels, or with some after-effects, inter-individually variable in amplitude and duration.

Electrophysiological parameters characterizing ventricular repolarization have repeatedly been shown in studies reviewed by Ruttkay-Nedecký (2001) (18) to carry information on

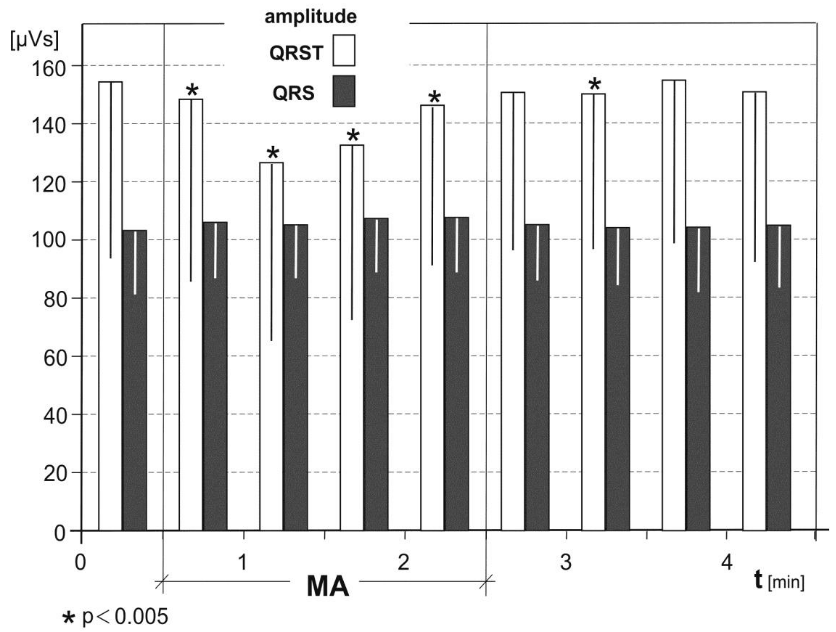

Figure 2 Mean group values ± SD of QRST ampl and QRS ampl, averaged in 30 s intervals during the MA test (N = 9). Time scale unit –1 minute.
*significant compared to rest before MA

the direct effect of sympathetic activation on the ventricular myocardium - in particular due to psycho-emotional load, active coping tasks to aversive stimuli, smoking or upright posture. In line with this concept are comparable changes of repolarization obtained after administration of adrenergic agonists (19, 20), or an opposite effect of beta-receptor antagonists (20, 21).

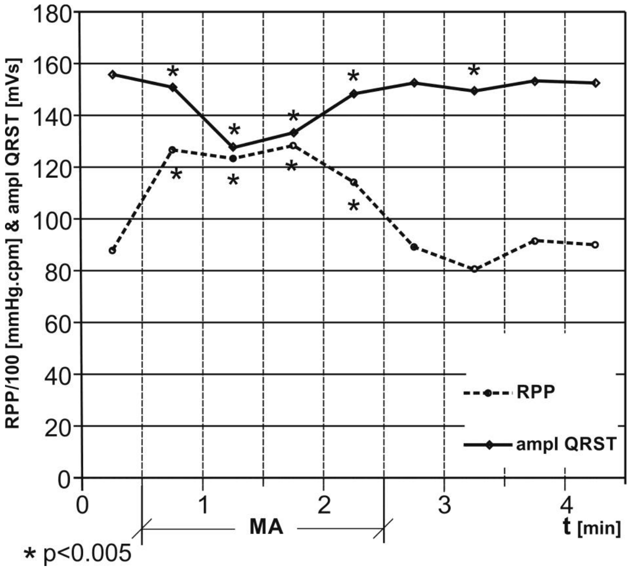

Figure 3 The mean values of the rate-pressure product gradually increase during the mental arithmetic test, in contrast to simultaneously decreasing QRSTampl (N = 9). Time scale unit –1 minute
*significant compared to rest before MA

The cardiovascular response to the forced MA was accompanied by marked changes in the BSPMs time integral pattern, most pronounced in the repolarization phase and contributing mainly to the alteration of ST and QRST integrals maps, as indicated by the respective significances. Reactive changes in the repolarization BSPMs presented in this study are in general agreement with previous VCG studies, documenting selected single beats significant diminution of the maximal spatial T-vector (4) or a reduction in T-wave amplitude (3, 21) during an active mental task in healthy subjects. Disposition to this type of response can vary widely in different people. In the present study, it appeared in about 2/3 of preliminary investigated subjects, as in another study (4). The rate-pressure product i.e. the product of simultaneous HR and systolic BP, as an indirect estimate, indicated at the same time an explicit increment of left ventricular performance.

It is concluded that all these findings may be explained by a stimulus specific pattern of the sympathetic response, which involves selective activation of the ventricular myocardium. The greatest norepinephrine spillover in reaction to cognitive challenge situations was documented by Esler et al. (22) from the heart (where its release almost trebled), compared to other sampling sites. In contrast to cardiac depolarization characterized by a wave-front propagation, the widely spatially and temporally spread myocardial repolarization processes may be more sensitive to subtle changes in the neurohumoral interactions at the membranes of the cardiac muscle cells, induced by sympathetic activation. The result is an improved homogeneity of ventricular recovery (23), and ultimately a highly significant decrease of the BSPMs QRST and ST amplitudes, increased angle a and lower NDI(ST).

Periodic variations in the repolarization BSPMs parameters in the low frequency (LF) band are similar to the many times described LF variations in heart rate, blood pressure or vasomotor activity. We support the hypothesis that LF component of BSPMs variability constitutes a marker of oscillations in the sympathetic drive of ventricles. It has been suggested that the same events that relate to a burst of sympathetic impulses in peripheral nerves also change cardiac autonomic outflow (24). Recently the periodic ventricular repolarization duration variability, when assessed in the LF band, was suggested to be used to infer cardiac sympathetic control (25).

Although body surface potential mapping is not regularly used in clinical practice, it has been suggested for decades as a potentially better way to identify depolarization and repolarization abnormalities of the heart. It has considerable potential, documented also in this study, to assess the effect of different physiological situations involving autonomic nervous system fluctuations, on the ventricular myocardium in normal healthy individuals, and in patients with various cardiovascular and non-cardiovascular diseases (6, 9 – 15). The substantial technical improvement of the BSPM recording and computer processing of the large amount of data find the chance in BSP mapping to be reintroduced in physiological research, and step-by-step also in clinical practice.

Ongoing clinical research continues to emphasize the role of BSPM in the non-invasive diagnostic assessment of the acute cardiac ischemia: to localize and estimate the size of the ischemic myocardial region (13, 26 – 32), as well as the characterization of an arrhythmogenic substrate in the myocardium, its location and analysis of trajectories (33 – 35). In some of the diagnostic procedures the method of difference BSPM was used, computed in the same subject from several BSPMs at rest, and for instance BSPMs at exercise, or with and without ischemia, or in comparison to the averaged BSPM from a control sample of healthy subjects. There are no studies but one (36) dealing with the beat-to-beat course of the dynamic modulation of the myocardial activation during the integrated cardiovascular responses to stress.

Conclusions

Although the low number of investigated subjects limits the immediate clinical application of the results, we would like to call attention to the following points.

Beat-to-beat analysis of QRS and QRST integral BSPMs provided an insight into the reactive modulation of the myocardial depolarization and repolarization due to a stressing situation.

Significant variability of the reactive changes of the integral BSPMs parameters, provoked by a cognitive task (MA), indicates the possibility of discovering subjects with abundant sympathetic effect on the ventricular myocardium and higher risk of ventricular dysfunction.

Unrecognized triggers of the sympathergic cardiac stress responses (hidden emotions, uncomfortable feeling, annoying imagination, white coat effect, cold, etc.), mainly influencing the repolarization process, may account for unwanted false positive findings in patients, or by provoking BSPM changes in reference subjects influence the resulting difference BSPMs.

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