# ST-segment changes in high-resolution body surface potential maps measured during exercise to assess myocardial ischemia: a pilot study

Michał Kania[1], Rajmund Zaczek[2], Heriberto Zavala-Fernandez[1], Dariusz Janusek[1], Małgorzata Kobylecka[3], Leszek Królicki[3], Grzegorz Opolski[2], Roman Maniewski[1]

[1]Nalecz Institute of Biocybernetics and Biomedical Engineering, Polish Academy of Sciences, Warsaw, Poland
[2]I Chair Department of Cardiology, Medical University of Warsaw, Warsaw, Poland
[3]Department of Nuclear Medicine, Medical University of Warsaw, Warsaw, Poland

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**Corresponding author:**
Michał Kania PhD
Nalecz Institute
of Biocybernetics and
Biomedical Engineering
Polish Academy of Sciences
4 Ks. Trojdena St.
02-109 Warsaw, Poland
Phone: +48 22 592 59 10
Fax: +48 22 659 70 30
E-mail: mkania@ibib.waw.pl

## Abstract

**Introduction:** The aim of the study was to assess myocardial ischemia by analysis of ST-segment changes in high-resolution body surface potential maps (HR-BSPM) measured at rest and during an exercise stress test.
**Material and methods:** The study was carried out on a group of 28 patients with stable coronary artery disease and 15 healthy volunteers. The HR-BSPM were measured at rest and during the exercise stress test on a supine ergometer. The workload was increased in stages by 25 W every 2 min, beginning at 50 W. The maps of ST-segment depression ($ST_{60}$) were calculated from time averaged recordings at rest and at maximal workload.
**Results:** The efficiency in detection of myocardial ischemia was higher for HR-BSPM than for standard 12-lead electrocardiography (ECG) when both methods were evaluated by outcomes of coronarography. The sensitivity of HR-BSPM was 82.4% while for the standard 12-lead ECG exercise stress test it was 58.8%. For some patients significant changes in the ST segment were observed at stress HR-BSPM but were not visible in standard 12-lead ECG recorded under the same conditions.
**Conclusions:** Obtained high values of sensitivity and specificity in myocardial ischemia detection suggest that maps of $ST_{60}$ calculated from HR-BSPM can improve detection of patients with ischemic heart disease in comparison to the standard electrocardiographic exercise stress test examinations.

**Key words:** exercise test, body surface potential mapping, ST segment, coronarography.

## Introduction

It is estimated that in European countries heart diseases are responsible for around 40% of cases of death before age 74 years [1, 2]. The high mortality rate among men and women [3–5] justifies the need to search for new diagnostic methods which ensure high sensitivity and specificity in detection of myocardial ischemia.

The standard 12-lead electrocardiographic (ECG) exercise stress test is one of the most commonly used noninvasive screening tests in patients with suspected stable coronary artery disease (CAD). Standard ECG has however limited sensitivity (30–70%) and specificity (70–95%)

in detection of CAD acute coronary syndromes [6]. To improve effectiveness of the ECG, diagnostic high-resolution measurement technique and body surface potential mapping were proposed [7, 8] and validated [9–11]. High-resolution body surface potential mapping (HR-BSPM) gives a more complete view of the electrical activity of the heart, compared to 12-lead ECG [12–18]. According to our studies, ischemic changes in the ECG signal are observed in the electrodes located outside the standard electrode positions (with no significant changes visible in standard ECG leads) [9, 11, 19, 20]. Michaelides *et al.* [21] demonstrated that an increase of ECG lead number during exercise testing increases sensitivity of detection of one-vessel coronary artery disease. Additional non-standard posterior ECG leads may also be useful in diagnosis of acute infarction [22]. This suggests that the high-resolution ECG mapping can bring new significant information about the state of cardiac muscle, contributing to a better diagnosis of coronary artery disease.

Currently, the most widely used marker of ischemic changes in a standard ECG exercise test is ST-segment depression. The aim of the study was to assess myocardial ischemia by analysis of the ST segment in high-resolution body surface potential maps (HR-BSPM) measured at rest and during an exercise stress test. To validate HR-BSPM diagnostic value the outcome of coronarography examination was used.

## Material and methods

The study group consisted of 28 male patients with stable coronary artery disease confirmed by coronarography. Additionally, 15 healthy volunteers (males) with no history of cardiovascular diseases were studied. Healthy subjects had normal resting 12-lead electrocardiograms as well as no symptoms of cardiovascular diseases in the 12-lead ECG exercise stress test. Basic statistical data of the study and control groups are presented in Table I.

All patients were in sinus rhythm, without intraventricular conduction abnormalities or left ventricular hypertrophy. The ECG signals were measured at rest and during an exercise test on a supine ergometer. The conventional 12-lead electrocardiograms (Cardiovit AT-104, Shiller) were recorded. Additionally, the 67-channel high-resolution ECG measurement system was used (ActiveTwo, Biosemi). ECG electrodes were placed on the thorax surface according to the modified Amsterdam lead system [8, 23], as shown in Figure 1 A. The workload was increased in stages by 25 W every 2 min, beginning at 50 W. Tests were terminated when the heart rate reached at least 85% of the maximal predicted value or due to chest pain, fatigue, arrhythmias, or marked ST-segment change. The study protocol was approved by an institutional ethical committee in accordance with the Declaration of Helsinki and informed consent was obtained from each patient. The additional results of stress technetium-99m sestamibi single-photon emission computed tomography (SPECT) with dipyridamole injection were obtained for two patients from the study group.

Baseline wander was reduced using the third-degree polynomial method [24] (with isoelectric levels estimated from the PR intervals). Independent component analysis and cardiac beats averaging in time were applied to reduce motion artifacts [23, 25]. Two sets of averaged ECG signals were computed: the first from a 10 min recording at rest and the second from a 10 s interval just before cessation of exercise. ECG fiducial points (Figure 1 B) detection was based on analysis of root-mean-square signal (the procedure was described in [23]). The amplitude of ST-segment 60 ms after the J point ($ST_{60}$) was measured for each electrode position and the distribution of obtained values on the thorax surface was estimated [26]. The 12-lead ECG exercise stress test was evaluated for the presence of myocardial ischemia according to current guidelines of the European Society of Cardiology [27]. According to the above-mentioned guidelines, in our body surface potential maps the exercise-induced ST-segment depression was considered significant (ischemia detected) if $ST_{60}$ was ≤ 0.1 mV in one or more anatomically contiguous body surface ECG leads.

Sensitivity, specificity, positive and negative predictive values of conventional 12-lead ECG and HR-BSPM in detection of myocardial ischemia were computed and compared to the results of coronarography examination.

**Table I.** Basic characteristics for study population

| Parameter | Characteristics |
|---|---|
| Age, study group [year] | 65 ±7 (51–79) |
| Age, control group [year] | 62 ±12 (45–77) |
| BMI, study group [kg/m$^2$] | 26.25 ±4.01 (19.37–36.09) |
| BMI, control group [kg/m$^2$] | 27.69 ±3.17 (20.96–32.93) |
| LAD/LCX/RCA occluded, *n* | 6/5/5 |
| Single-vessel disease, *n* | 11 |
| Multivessel disease[a], *n* | 2 |
| No significant[b] changes in coronary arteries, *n* | 15 |

*BMI – body mass index, LAD – left anterior descending artery, LCX – left circumflex artery, RCA – right coronary artery; [a]two or more significant stenosed major coronary arteries; [b]greater than 70% stenosis in major coronary arteries was classified as significant.*

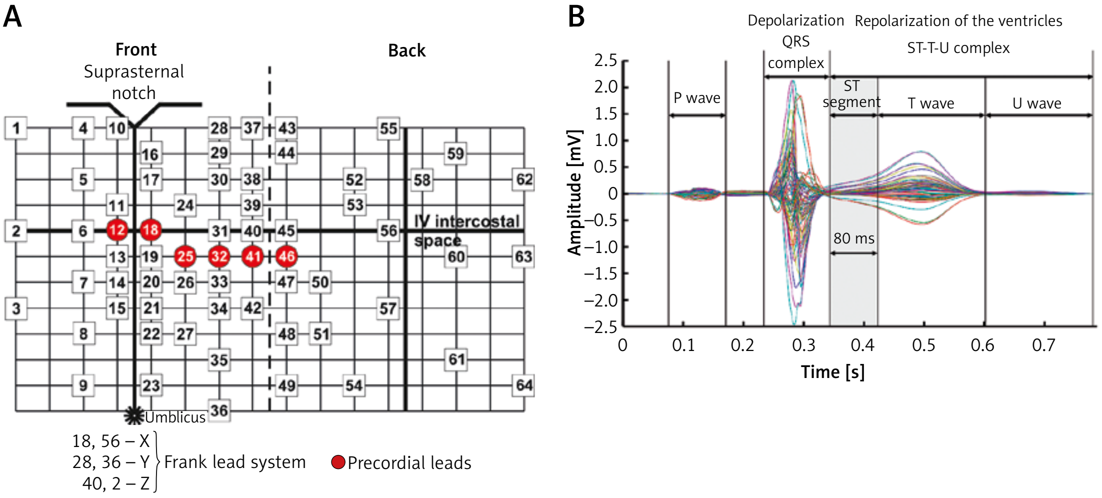


**Figure 1.** Recording and preprocessing of multilead ECG signals. **A** – ECG electrode arrangement on the thorax surface, **B** – time-averaged ECG signals from all recorded leads

**Table II.** Sensitivity and specificity in detection of myocardial ischemia at exercise stress test

| Diagnostic method | Sensitivity [%] | Specificity [%] |
|---|---|---|
| Standard 12-lead ECG | 58.8 | 100 |
| HR-BSPM | 82.4 | 86.6 |

## Results

The results of the study are presented in Table II and Figure 2. The representative distributions of $ST_{60}$ values on the thorax surface for one healthy volunteer as well as for two patients with and without significant exercise-induced changes in the ST segment are shown in Figure 2. The reference maps of ST-segment amplitude computed from rest ECG recordings and $ST_{60}$ values observed during maximal effort are presented. The red (blue) color corresponds to the maximum (minimum) $ST_{60}$ values calculated from all ECG lead positions. The patients for which the significant changes of $ST_{60}$ in HR-BSPM maps were shown in Figures 2 A and 2 B had ischemia detected in coronarography but not in standard 12-lead ECG. The additional

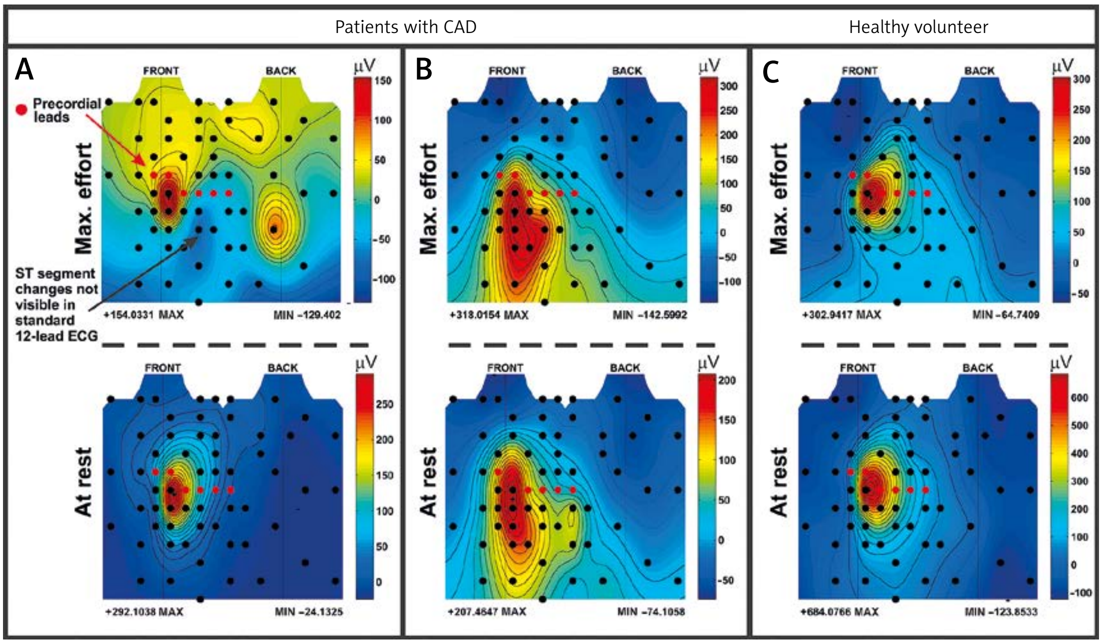


**Figure 2.** Body surface maps of ST-segment amplitude 60 ms after J point computed from averaged in time multilead ECG recordings of patients with stable coronary artery disease (**A, B**) and healthy volunteer (**C**). The significant (A) and non-significant (B, C) ST-segment changes in BSPM due to exercise are shown. Presented maps were obtained from ECG signals recorded at rest and at maximal effort. The patients had ischemia detected by coronarography and additionally by SPECT examination but not in a standard 12-lead ECG stress test

performed SPECT studies confirmed ischemia detection for these 2 patients.

The values of sensitivity and specificity in detection of patients with coronary artery disease according to the outcome of coronarography examination are shown in Table II.

In the study group 15 (54%) positive and 13 (46%) negative findings of ischemia symptoms were obtained by using conventional 12-lead ECG. Twenty (71%) patients and 8 (29%) patients were classified by HR-BSPM respectively as with and without myocardial ischemia. In the control group all subjects were classified as healthy if occurrence of ischemia symptoms was judged by standard 12-lead ECG. Two subjects from the control group had a positive result of HR-BSPM. The positive and negative predictive values in the case of 12-lead ECG were 67% and 46%, respectively. The positive predictive value of 70% and negative predictive value of 63% was obtained if presence of ischemia was evaluated by HR-BSPM.

## Discussion

The efficiency in detection of myocardial ischemia was higher for HR-BSPM than for standard ECG when both methods were evaluated by outcomes of coronarography. In the obtained results the sensitivity of the proposed method based on analysis of the ST-segment amplitude in HR-BSPM recorded during the exercise stress test was 82.4% while for the standard 12-lead ECG exercise stress test it was 58.8%. The main reason for the higher values of sensitivity in detection of patients with myocardial ischemia obtained for HR-BSPM in comparison to standard 12-lead ECG was the larger number of ECG leads. In this study, for some patients ischemic changes in the ST segment were observed in leads positioned outside the precordial area whilst no significant changes were visible in precordial leads (Figure 2 A). This was also reported previously by other research groups working on multilead ECG recordings [28–30]. Montague *et al.* [31] studied the body surface potential maps of the ST-segment integrals during exercise testing. They found that marked ST-segment changes are observed not only over the precordium but also in the entire lower torso.

The lack of perfect accordance of HR-BSPM and coronarography results in detection of patients with stenosed arteries could be due to the fact that stenosis of main coronary arteries does not necessarily indicate significant low perfusion of the myocardium due to microvasculature, or formation of "natural bypasses" i.e., collateral vessels. This hypothesis could be examined using the scintigraphy method (by comparison with HR-BSPM). The specificity was lower for HR-BSPM (86.6%) than for the standard 12-lead ECG exercise stress test. Significant changes in the ST segment were observed for two subjects from the control group in leads which were not included in the conventional 12-lead ECG electrode layout. Montague *et al.* [31] found qualitatively similar but quantitatively less severe exercise-induced ST-segment changes in normal subjects compared to CAD patients. They concluded that there should be a quantitative and temporal continuum of myocardial metabolic changes from physiologic exercise to ischemia and recovery [31]. The ischemic changes observed could also indicate existence of silent ischemia. It was reported [32–35] that significant ST-segment depression may occur in 10–30% of the normal population.

The obtained results suggest that increased ECG lead number, higher amplitude resolution of BSPM and application of advanced methods of noise reduction allow for better recognition of myocardial ischemia than the routinely performed standard 12-ECG lead exercise stress test. The results of this pilot study should be confirmed by further investigation on a larger number of studied patients.

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