Possibilities of signal-averaged orthogonal and vector electrocardiography for locating and size evaluation of acute myocardial infarction with ST-elevation

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ABSTRACT

Objective: The signal-averaged electrocardiography (SAECG) is known to be a useful tool for extraction and analysis of low-amplitude signal components. We found SAECG may be useful for precise location of the site of the myocardial necrosis and assessment of the severity of impaired left ventricular systolic function of patients with ST-elevation myocardial infarct (STEMI) in the acute phase.

Methods: High-resolution (1 MHz) ECG from 3 groups were collected: healthy controls (20), patients with anterior (17) and inferior STEMI (21). The three orthogonal leads X, Y, Z were synthesized from the 12 standard leads by known transformation. Synchronized averaging was carried out over hundred P-QRS-T intervals of each orthogonal lead. The resulting intervals of all subjects within a group were additionally averaged. The obtained X, Y and Z patterns, as well as the derived loops in the vectorcardiographic planes (VCG patterns) were studied for significant divergences.

Results: The summarized analysis presenting the possibilities of QRS- and T-vector indicators for correct classification of patients with STEMI shows that the determined discriminators classify correctly 91.4% of the examined patients. The optimized set of QRS-vector indicators for discrimination between healthy controls and patients with inferior STEMI include angle α of the maximal vector in both the sagittal and the horizontal plane. These two indicators show as high predictive value as all QRS-vector indicators – 82.9%. The optimized combination of QRS-vector indicators for discrimination between healthy controls and patients with anterior STEMI includes amplitude of the maximal vector in the frontal and sagittal planes, angle α of the maximal vector in the sagittal plane and the area of the loop in the frontal plane. This optimized combination has a common mean percentage of correctly classified patients of about 91.9%. The accuracy for infarct zone localization is improved with optimized combinations involving together QRS- and T-vector indicators. The achieved common mean percentages of correct classifications are 94.6% (healthy controls-anterior STEMI), 92.7% (healthy controls-inferior STEMI) and 97.4% (anterior STEMI-inferior STEMI). The set of all QRS-and T-vector indicators of patients with anterior STEMI regarding 2D-echocardiographic ejection fraction shows very high correlation coefficient, reaching about 0.99. In contrast, we did not find significantly high correlation in patients with inferior STEMI.

Conclusions: Both the signal-averaged orthogonal ECG and the synthesized on its basis VCG show markedly high sensitivity regarding location of ST-elevation myocardial infarct. The possibility for facilitated and fast performance of this examination in clinical conditions, including emergency, the lack of necessity of specially trained staff for carrying out the examination and interpretation of the results, as well as the very low prime cost, make this electrophysiological method very suitable for application in the routine clinical practice for qualitative and quantitative assessment of patients with acute coronary syndromes. *(Anadolu Kardiyol Derg 2007: 7 Suppl 1; 193-7)*

Key words: high-resolution signal-averaged electrocardiography, synthesized orthogonal electrocardiography, vectorcardiography, acute myocardial infarction.

Introduction

In principle, the signal-averaged high-resolution electrocardiography (SAECG) is a technique involving computerized analysis of small segments of a standard electrocardiography (ECG) in order to detect late potentials (1, 2). It allows subtraction and analysis of low-amplitude components in the signal, containing important diagnostics information, but inadmissible for analysis using conventional 12-channel ECG. The high resolution SAECG and vectorcardiography (VCG) were employed recently as methods for qualitative and quantitative diagnosis of patients with acute myocardial infarction (AMI). The existing scarce data in worldwide literature about quantitative assessment of patients with AMI by SAECG suggest very high diagnostic value of this method (3-6). In this research, we studied the possibilities to create standards, characterizing ST-elevation myocardial infarction with different location and size using synthesized from SAECG orthogonal X, Y and Z leads and VCG loops.

Methods

ECG Data

High-resolution (1 MHz sampling rate) ECG recordings were collected by 12-channel ECG data acquisition system (7) at the intensive coronary unit. The following groups were included in the study:

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- 38 patients with clinical symptoms, ECG and laboratory data indicating acute coronary syndrome with ST-elevation (STEMI), who were admitted within 48 hours of the beginning of angina pain. The patients were classified according to the STEMI localization in 2 groups, including 17 patients with inferior STEMI and 21 patients with anterior STEMI. Each patient was examined by 2-dimensional echocardiography (2D-Echo) and left ventricular ejection fraction (EF) was measured (by Simpson's rule), aiming to determine the correlation between the electrophysiological changes and the degree of left ventricular systolic dysfunction
- 20 healthy subjects.

ECG analysis

A software system for ECG signal analysis and visualization was developed in Matlab 7.0 (The Mathworks Inc.). The ECG signal analysis module incorporated:

- Synthesis of the three orthogonal Frank leads X, Y, Z (OECG) by known mathematical transformations (8) involving the high-resolution recordings of the 12 standard ECG leads, as follows:

$$X = 0.4*II - 0.8*(II + III)/3 + 0.2*V5 + 0.5*V6 + 0.1*V4 \quad (1)$$
$$Y = 0.3*III + 0.8*II + 0.5*(II + III)/3 - 0.2*V5 - 0.3*V6$$
$$Z = -0.1*III - 0.2*II + 0.4*(II + III)/3 - 0.3*V1 - 0.1*V2 - 0.1*V3 - 0.2*V4 - 0.1*V5 + 0.4*V6$$

- QRS-detection and localization of P, QRS, T waves for each cardiac cycle;
- Detector of supraventricular and ventricular ectopic beats;
- A synchronized averaging of all normal P-QRS-T intervals in each OECG lead (not less than 50, mean of about 100 intervals, excluding all supraventricular and ventricular extrasystoles). Thus, we obtained a patient-specific high-resolution X, Y, Z patterns, which are representative for the most stable QRS, ST and T-changes, reflecting the actual electrophysiologic condition of the patient's myocardium. We achieved the advantage of signal-averaging that is the significant diminution of some delusive changes within the X, Y, Z patterns due to both extracardiac noise influences and interbeat variances;
- Construction of spatial VCG loop from the high-resolution X, Y, Z patterns and derivation of its projections in the horizontal, sagittal and transverse VCG planes (VCG patterns). The signal-averaged VCG patterns typical for the patient feature with noise-free and stable QRS and T-loops.
- Measurement of a set of geometrical indicators of the high-resolution VCG patterns, including: QRS_{MAX}, QRS_{α} – amplitude and angle of the QRS-loop maximal vector; QRS_{AR} – area of the QRS-loop; T_{MAX}, T_{α} – amplitude and angle of the T-loop maximal vector; T_{AR} – area of the T-loop.

Statistical analysis

The measurements of the defined set of VCG pattern descriptors, as well as the EF for all patients were involved into statistical analysis. The derivation of optimal classification set of VCG pattern descriptors, in relation to the infarct localization, was obtained with stepwise linear discriminant analysis. Thus, the method automatically selects the VCG pattern descriptors that have statistical significance in the discrimination between the groups for MI localization.

The multiple regression analysis of the VCG pattern descriptors was applied for verification of the possibility to predict the EF and therefore the infarct size. We applied stepwise selection of predictor variables, which were chosen among defined subsets of VCG pattern descriptors.

Results

First, we performed averaging of the patient-specific scalar X, Y, Z patterns over all patients included in one group. Thus for the three groups – healthy controls, anterior and inferior AMI, we obtained a specific averaged X, Y, Z patterns and defined a variable named "envelope" which represents the limits of quantitative variation of the morphological orthogonal ECG components (Fig.1).

The second step included averaging of the patient-specific VCG patterns over all patients within each of the three groups. Figure 2 represents the VCG patterns in the three VCG planes for each patient (the gray lines), as well as the averaged VCG-patterns within a group (the bold line). The same scaling is used for all vector

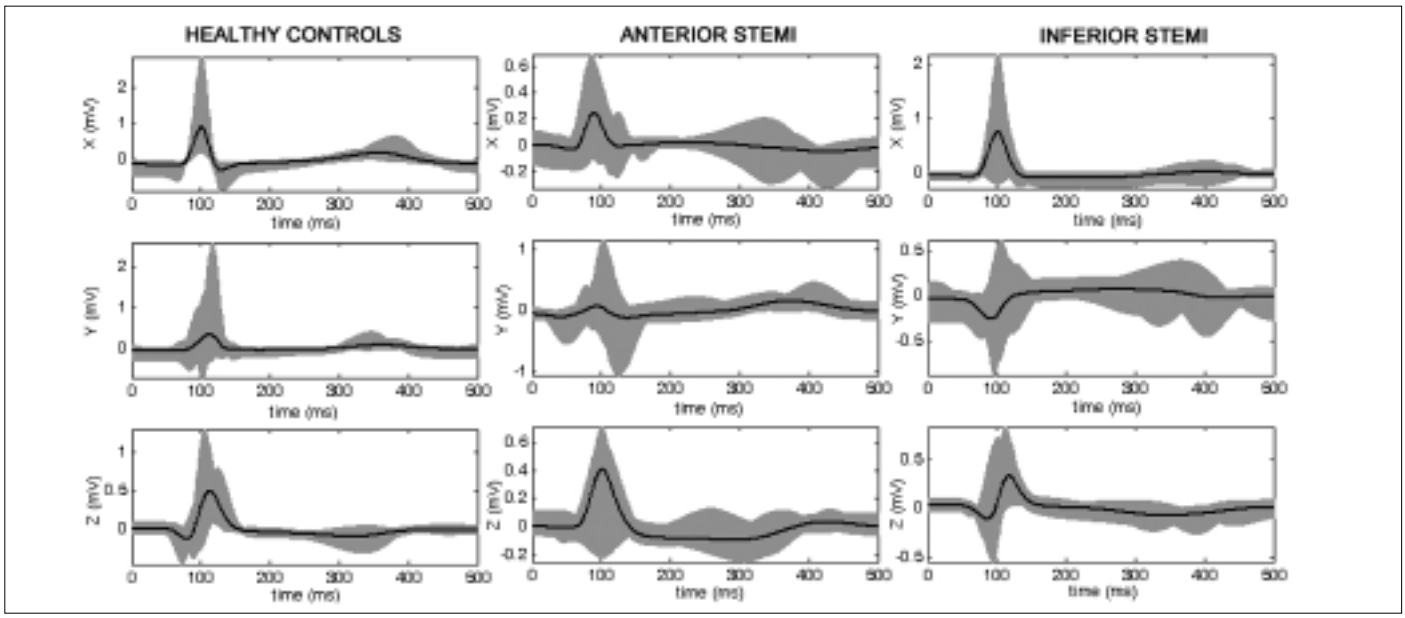

Figure 1. High-resolution X, Y, Z patterns for the three studied groups of patients. The black line represents the averaged pattern signal. The gray-scale surrounding regions are the limits of quantitative variation of the signal among the patients with STEMI and healthy subjects

STEMI- ST-elevation myocardial infarction

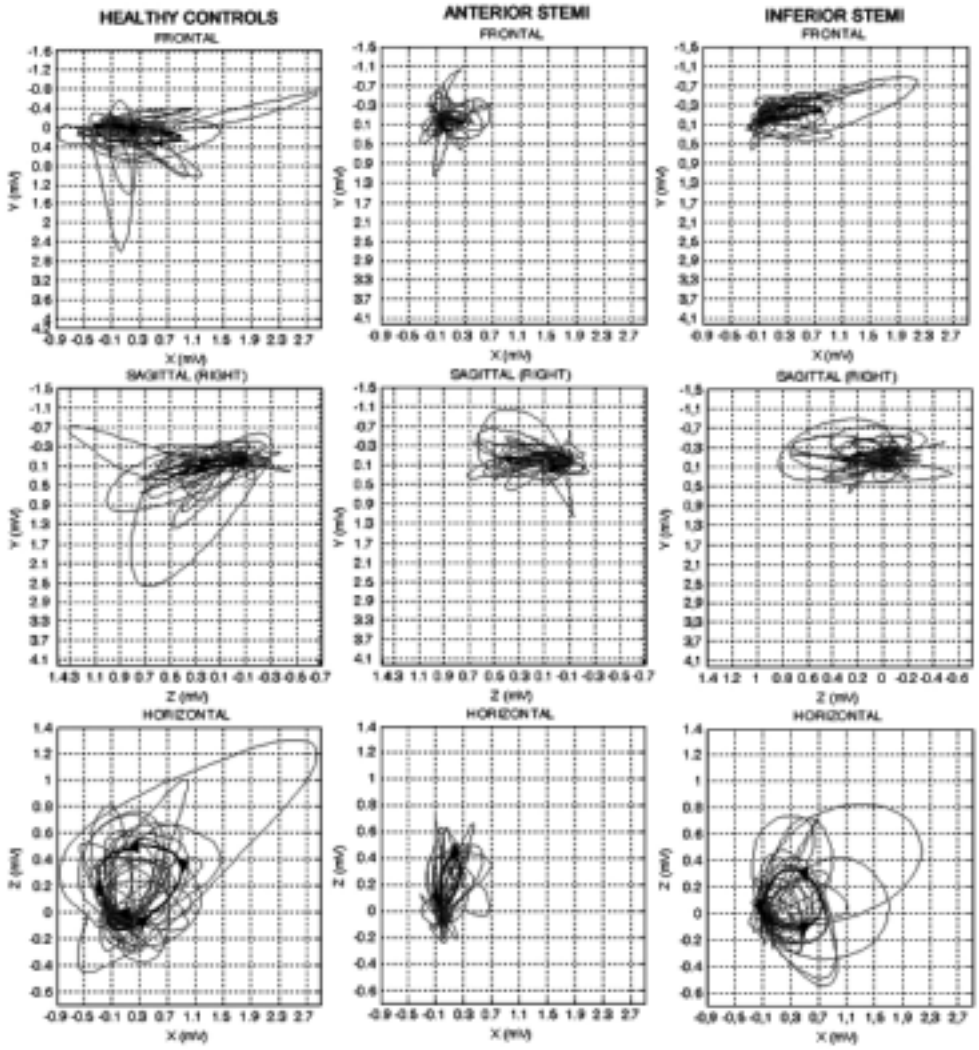

Figure 2. Projection of the VCG patterns in the three VCG planes for of all subjects: healthy controls and patients with anterior and inferior STEMI. The gray lines are the VCG patterns measured for each patient. The thick black line represents the averaged VCG pattern of the examined group
STEMI- ST-elevation myocardial infarction, VCG- vectorcardiography

Table 1. Estimation over the averaged VCG patterns (in frontal, sagittal and horizontal projection) for the three studied groups of patients: values of the geometrical indicators defined for the QRS- and T-vectors

		VCG FRONTAL			VCG SAGITTAL			VCG HORIZONTAL		
		Ampl Max, mV	α Max, deg	Area, mV²x1000	Ampl Max, mV	α Max, deg	Area, mV²x1000	Ampl Max, mV	α Max, deg	Area, mV²x1000
QRS-vector	Healthy	0.91	16.03	311.18	0.60	33.02	58.96	0.95	23.20	543.42
	Anterior STEMI	0.24	9.68	0.26	0.40	4.14	41.00	0.43	60.89	67.48
	Inferior SREMI	0.78	287.0	140.48	0.32	282.55	64.60	0.72	14.91	287.95
T-vector	Healthy	0.21	22.46	9.44	0.10	133.70	8.61	0.20	291.6	17.34
	Anterior STEMI	0.15	167.8	8.65	0.13	82.94	20.72	0.06	125.8	1.73
	Inferior STEMI	0.12	126.4	5.79	0.10	129.49	7.12	0.06	340.9	9.72

deg- degree, max- maximum, STEMI- ST-elevation myocardial infarction, VCG- vectorcardiography

images in order to facilitate the visual marking of the differences between each group of patients. The measurements of the geometrical indicators of the averaged VCG patterns for each group are listed in Table 1.

Standard discriminant analysis was applied over all indicators of the QRS and T vectors (QRSMAX, QRSα, QRSAR, TMAX, Tα, TAR) in the three VCG projections for classifications of the patients within one of the studied groups. The results are presented in Table 2.

Stepwise linear discriminant analysis was applied to derive the optimal classification set of VCG indicators that have statistical significance in the discrimination between the groups for MI localization and healthy controls. The results are presented in Table 3.

Table 2. Results from standard discriminant analysis: adjusted percentage of correct classification of patients with STEMI using all indicators of the QRS- and T-vectors (in frontal, sagittal and horizontal projection)

All indicators of the VCG patterns in the 3 VCG planes	Adjusted % of correct classifications			
	Healthy controls, %	Anterior STEMI, %	Inferior STEMI, %	Common mean, %
QRS-vector	80.0	76.5	66.7	74.1
T- vector	80.0	64.7	85.7	77.6
QRS- and T-vectors	90.0	94.1	90.5	91.4

STEMI- ST-elevation myocardial infarction, VCG- vectorcardiography

Table 3. Results from stepwise linear discriminant analysis: Accuracy for correct discrimination between different groups of patients and a list of the optimal set of QRS-and T-vector descriptors (designated with F – frontal plane, S- sagittal plane, H-horizontal plane)

	Comparison by groups	Correct classification in G1	Correct classification G2 in	Common mean % of correct classifications	Set of descriptors of the VCG patterns in the 3 VCG planes
ONLY QRS- vector indicators	G1: Healthy controls	90.0%	94.1%	91.9%	All descriptors of the QRS-loop
	G2: Anterior STEMI	90.0%	94.1%	91.9%	Optimized combination: QRSFMAX, QRSSα, QRSSMAX, QRSFAR
	G1: Healthy controls	85.0%	81.0%	82.9%	All descriptors of the QRS-loop
	G2: Inferior STEMI	80.0%	85.7%	82.9%	Optimized combination: QRSSα, QRSHα
	G1: Anterior STEMI	94.1%	80.9%	86.8%	All descriptors of the QRS-loop
	G2: Inferior STEMI	100.0%	71.4%	84.2%	Optimized combination: QRSHAR, QRSSMAX, QRSHα, QRSFMAX, QRSHMAX
ONLY T- vector indicators	G1: Healthy controls	95.0%	100.0%	97.3%	All descriptors of the T-loop
	G2: Anterior STEMI	95.0%	88.2%	91.9%	Optimized combination:
					TSAR, THMAX, TFα, TSα, THAR
	G1: Healthy controls	85.0%	95.2%	90.2%	All descriptors of the T-loop
	G2: Inferior STEMI	90.0%	90.5%	90.2%	Optimized combination: TFα, THMAX, TSAR, TFMAX, THAR
	G1: Anterior STEMI	64.7%	95.2%	81.6%	All descriptors of the T-loop
	G2: Inferior STEMI	70.6%	90.5%	81.6%	Optimized combination: THα, TSα, TSAR, TFAR
QRS- and T-vector indicators	G1: Healthy controls	95.0%	100.0%	97.3%	All descriptors of the QTS - and T-loop
	2: Anterior STEMI	95.0%	94.1%	94.6%	Optimized combination: QRSFMAX, TFα, TSAR, TSα, QRSSMAX, QRSFα
	G1: Healthy controls	95.0%	95.2%	95.1%	All descriptors of the QTS - and T-loop
	G2: Inferior STEMI	90.0%	95.2%	92.7%	Optimized combination: QRSSα, TFα, QRSHAR, THα, TFMAX, TSAR, QRSHα, QRSHMAX
	G1: Anterior STEMI	100.0%	95.2%	97.4%	All descriptors of the QTS - and T-loop
	G2: Inferior STEMI	100.0%	95.2%	97.4%	Optimized combination: THa, QRSHAR, QRSSMAX, THAR QRSFMAX, QRSHa, QRSHMAX, TSAR, TFAR, THMAX

STEMI- ST-elevation myocardial infarction, Ta- angle of the T-loop maximal *vector,* TAR- area of the T-loop, TMAX- amplitude of the T-loop maximal vector, QRSα- angle of the QRS-loop maximal vector, QRSAR- area of the QRS-loop, QRSMAX- amplitude of QRS-loop maximal vector, VCG- vectorcardiography

Table 4. Results from multiple regression analysis: selected subsets of VCG pattern indicators that most accurately predict EF (%) in the acute phase of anterior and inferior STEMI

STEMI Group	VCG loop	VCG Indicators	Regression Summary
ANTERIOR STEMI	QRS	QRSSMAX, QRSFAR	Adj.R2=0.15; F=2.41; p<0.126; SEE=9.92
	T	TFMAX*, THα*, TSα, THMAX, TFα, TFAR	Adj.R2=0.373; F=2.59; p<0.088; SEE=8.52
	QRS+T	TFMAX*, THα*, TSα*, QRSHAR*, THMAX*, QRSFAR*, QRSFMAX*, QRSSα*, QRSSAR*, QRSSMAX, TSAR, QRSFα, TSMAX, TFα, THAR	Adj.R2=0.9989; F=968.8; p<0.025; SEE=0.357
INFERIOR STEMI	QRS	QRSHAR*	Adj.R2=0.147; F=4.45; p<0.0483; SEE=6.63
	T	TSMAX*, THα	Adj.R2=0.185; F=3.27; p<0.0615; SEE=6.48
	QRS+T	TSMAX*, THα	Adj.R2=0.185; F=3.27; p<0.0615; SEE=6.48

* - VCG indicator with statistical significance (p<0.05) in the regression;
Adj.- adjusted, EF- ejection fraction, F- frontal, H- horisontal, S- sagittal, SEE- standard error of estimate, STEMI- ST-elevation myocardial infarction, T_a- angle of the T-loop maximal *vector,* TAR- area of the T-loop, TMAX- amplitude of the T-loop maximal vector, QRSα- angle of the QRS-loop maximal vector, QRSAR- area of the QRS-loop, QRSMAX- amplitude of QRS-loop maximal vector, VCG- vectorcardiography

Table 4 summarizes the optimized set of VCG indicators, determined by multiple regression analysis, showing highest degree of correlation between the electrophysiological changes, expressed by the vector variables and the severity of impaired left-ventricle pump function, assessed by 2D-Echo EF.

Discussion

The summarized analysis in Table 2 presenting the possibilities of QRS-and T-vector indicators for correct classification of patients with STEMI, shows that the determined discriminators classify correctly 91.4% of the examined patients.

The analysis of the QRS- and T-vector indicators in the 3 VCG planes shows high informative value regarding location of the myocardial necrosis. The optimized sets of vector indicators from each group have as high predictive possibilities as all defined VCG pattern descriptors applied together.

The optimized set of QRS-vector indicators for discrimination between healthy controls and patients with inferior STEMI include angle α of the maximal vector in both the sagittal and the horizontal plane. These two indicators show as high predictive value as all QRS-vector indicators – 82.9%.

The optimized combination of QRS-vector indicators for discrimination between healthy controls and patients with anterior STEMI includes amplitude of the maximal vector in the frontal and sagittal plane, angle α of the maximal vector in the sagittal plane and the area of the loop in the frontal plane. This optimized combination has a common mean percentage of correctly classified patients of about 91.9%. The same result is achieved after involving into analysis all QRS-vector indicators from the 3 VCG planes (Table 3).

The accuracy for infarct zone localization is improved with optimized combinations involving together QRS- and T-vector indicators. The achieved common mean percentages of correct classifications are 94.6% (healthy controls-anterior STEMI), 92.7% (healthy controls-inferior STEMI) and 97.4% (anterior STEMI-inferior STEMI).

The self-dependent predictive value of QRS- n T-vector indicators of patients with anterior STEMI (Table 4) regarding 2D-Echo EF is low - the correlation coefficient is 0.15 and 0.37, respectively. Combination of all QRS-and T-vector indicators, however, shows very high correlation coefficient, reaching about 0.99. In contrast, we did not find significantly high correlation between QRS-and T-vector indicators and EF in patients with inferior STEMI.

Conclusions

Both the signal-averaged orthogonal ECG and the synthesized on its basis VCG show markedly high sensitivity regarding location of ST-elevation myocardial infarction. The possibility for facilitated and fast performance of this examination in clinical conditions, including emergency, the lack of necessity of specially trained staff for carrying out the examination and interpretation of the results, as well as the very low prime cost, make this electrophysiological method very suitable for application in the routine clinical practice for qualitative and quantitative assessment of patients with acute coronary syndromes.

References

1. Pettersson J, Carro E, Edenbrandt L, Maynard C, Pahlm O, Ringborn M, et al. Spatial, individual, and temporal variation of the high-frequency QRS amplitudes in the 12 standard electrocardiographic leads. Am Heart J 2000; 139: 352-8.
2. Pu S. Quantitative analysis of signal-averaged electrocardiogram. Zhonghua Xin Xue Guan Bing Za Zhi 1991; 19: 281-4.
3. Abboud S, Belhassen B, Miller I, Sadeh D, Laniado S. High frequency electrocardiography using an advanced method of signal averaging for non-invasive detection of coronary artery disease in patients with normal conventional electrocardiogram. J Electrocardiol 1986; 19: 371-80.
4. Dennis A, Ross D, Uther J. Reproducibility of measurements of ventricular activation time using the signal-averaged Frank vectorcardiogram. Am J Cardiol 1986; 57: 156-60.
5. Pettersson J, Pahlm O, Carro E, Edenbrandt L, Ringborn M, Sornmo L, et al. Changes in high-frequency QRS components are more sensitive than ST segment deviation for detecting acute coronary artery occlusion. J Am Coll Cardiol 2000; 36; 1827-34.
6. Rosas M, Hermosillo AG, Infante O, Kuri J, Cardenas M. Relationship between the site of a myocardial infarction and signal-averaged electrocardiogram indices. Int J Cardiol 1998; 63: 129-40.
7. Iliev I, Tsvetanov D, Matveev M, Naidenov S, Krasteva V, Mudrov N. Implementation of high resolution wireless ECG data acquisition system in intensive coronary care unit. In: AITTH'2005. Proceedings of International Conference Advanced Information and Telemedicine Technologies for Health; 2005 Nov 8-10; Minsk, Belarus: 2005. p. 79-84.
8. Levkov C. Orthogonal electrocardiogram derived from the limb and chest electrodes of the conventional 12-lead system. Med Biol Eng & Comp 1987; 25: 155-64.