

ОРИГИНАЛЬНЫЕ СТАТЬИ • ORIGINAL ARTICLES

COMPARATIVE ANALYSIS AND ESTIMATION OF SENSITIVITY OF STANDARD SURFACE ECG
AND ECG FROM THE CORONARY SINUS TO INDUCED MYOCARDIAL ISCHEMIA

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Abstract. The aim of this study was to compare the sensitivity of ECG from the coronary sinus and standard surface ECG in verifying myocardial ischemia during interventions on coronary arteries.

The prospective study included 157 patients with coronary artery disease who, during coronary intervention, were monitored for ischemia using both an ECG from the coronary sinus and the traditional ECG technique with 3 standard and 3 enhanced leads. Analysis of the intracardiac ECG was performed using a WorkMate electrophysiological station (SJM), while analysis of the standard ECG was performed using a Datex-Ohmeda Cardiocap / 5 (GE) monitor.

The integral sensitivity of the surface ECG and the ECG from the coronary sinus to myocardial ischemia, without taking the stage of coronary intervention and the part of the coronary bed into account, was 32.4% and 84%, respectively.

The ECG from the coronary sinus method is more sensitive in relation to myocardial ischemia in comparison with the superficial standard ECG technique in the process of percutaneous coronary intervention.

Keywords: coronary heart disease (CHD), ECG, intracardiac ECG, ischemia monitoring.

Introduction

Electrocardiography (ECG) has long been a standard method of instrumental examination of patients due to the high level of evidence and wide possibilities for the diagnosis of various cardiac pathologies. The study of the topographic distribution of electrical potential on the surface of the human body led to the development of the traditional substantiation of instrumental ECG registration and the formation of the foundations of electrocardiogram analysis [1; 2; 3].

Since the 1960s, computer electrocardiography, clinical electrophysiology of the heart, and external electrocardiographic mapping have proved to be particularly promising directions for the development of electrophysiology [3; 4–11].

Further progress in electrophysiology is associated with the presentation of data based on the accepted mathematical model of the electric generator of the heart in biophysical and electrophysiological terms, with reference to the anatomical landmarks of the heart [1; 12; 13–15]. On this path, however, one has to face fundamental difficulties, primarily with the physical ambiguity of determining the cardiogenerator by the potential measured in the external region on the body surface [12; 16–21].

**СРАВНИТЕЛЬНЫЙ АНАЛИЗ И ОЦЕНКА ЧУВСТВИТЕЛЬНОСТИ
СТАНДАРТНОЙ МЕТОДИКИ ЭКГ И ЭКГ ИЗ ВЕНЕЧНОГО
СИНУСА К ИНДУЦИРОВАННОЙ ИШЕМИИ МИОКАРДА**

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Резюме. Целью настоящего исследования стало сравнение точности методов ЭКГ-ВС и стандартной поверхностной ЭКГ в верификации ишемии миокарда при эндоваскулярных вмешательствах на КА.

В исследование на проспективной основе было включено 157 больных ИБС, которым во время плановой коронарной интервенции производился мониторинг ишемии с помощью ЭКГ из венечного синуса и традиционной методики ЭКГ в 3 стандартных и 3 усиленных отведениях. Анализ внутрисердечной ЭКГ выполнялся с использованием электрофизиологической станции WorkMate (SJM), стандартной ЭКГ – монитора Datex-Ohmeda Cardiocap/5 (GE).

Интегральная чувствительность методов пЭКГ и ЭКГ-ВС к ишемии миокарда без учета этапа коронарной интервенции и бассейна КР составила 32,4% и 84% соответственно.

Метод ЭКГ-ВС является более чувствительным в отношении ишемии миокарда по сравнению с поверхностной стандартной методикой ЭКГ в процессе выполнения интервенционных вмешательств на коронарных артериях.

Ключевые слова: ишемическая болезнь сердца (ИБС), электрокардиография (ЭКГ), внутрисердечная ЭКГ, мониторинг ишемии.

At the Pirogov Center, academician of the Russian Academy of Sciences Yu.L. Shevchenko developed and introduced the method of electrocardiography from the coronary sinus (ECG-CS) into clinical practice in 2018. This method makes it possible to identify and accurately map the zones of myocardial ischemia (MyI) during percutaneous coronary intervention (PCI) [1; 2; 11–15; 18; 19]. The aim of the current work was to compare the accuracy of ECG-CS and standard surface ECG in verifying myocardial ischemia during percutaneous coronary interventions (PCI).

Methods

The prospect-based study included 157 patients with coronary heart disease (CHD), in whom the sensitivity of conventional ECG and ECG from the coronary sinus to detect myocardial ischemia was compared during PCI. All the patients signed an informed consent form to participate in the study and agreed to additional invasive manipulation, allowing doctors to insert an intracardiac electrode into the coronary sinus of the heart. We also received approval from the Pirogov Center's Local Ethics Committee.

Clinical criteria for inclusion in the study were: stable angina; myocardial ischemia, confirmed by stress tests; single-

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vessel lesion of the coronary bed (CB); and hemodynamically significant coronary artery stenosis according to CAG data.

The exclusion criteria were: unstable angina pectoris; initial disturbances of rhythm and conduction; mitral insufficiency of the III–IV degree; impaired renal function (creatinine level $> 200 \mu\text{mol/l}$); contraindications to standard antiplatelet therapy; prior bypass grafting procedures; and occlusive coronary artery disease.

Percutaneous coronary intervention was performed according to the standard technique, against the background of continuous ECG monitoring in 3 standard and 3 enhanced leads from the patient's extremities, with pulse oximetry and indirect blood pressure measured at intervals of 5–10 minutes using a Datex-Ohmeda Cardiocap / 5 multivariable configured monitor (GE).

ECG from the coronary sinus: method principle and equipment

According to theoretical and experimental models in the cardioelectric field, the formation of systolic and diastolic currents of myocardial damage during ischemia indicate four possibilities of potential distribution: the rest potential (RP) of the ischemic area is smaller (in modulus) than the RP of the area with normal perfusion — hypopolarization; the RP of the area of damage is higher (in modulus) than the RP of the area of normal perfusion — hyperpolarization; the excitation potential (EP) of the pathological area is less than the EP of the healthy area — hypodepolarization; or the EP of the damaged area is higher than that of the healthy area — hyperdepolarization. In this case, synergism of the first and third types of action potential displacement is possible.

The installation of an intracardiac electrode in the coronary sinus allows doctors to detect the potential difference across the cathode-anode electrode pairs at the time of a decrease in coronary perfusion, which is expressed on the intracardiac ECG leads as a displacement of the ST segment relative to the isoline. In this case, the amplitude of the deviation correlates to the degree of ischemia, and the direction of the deviation (depression or elevation) correlates to the localization of the ischemic focus and the charge of the damaged area.

In our study, we used the WorkMate electrophysiological recording system (St. Jude Medical) (EPRS) to carry out the invasive intraoperative analysis of ischemic infections.

Catheterization of the coronary sinus was performed through the subclavian and jugular, although in 52 patients (using the spent minimally invasive access) the process was done through the cubital vein with the installation of a 7F introducer. An intracardiac 10-channel CS electrode was placed in the coronary sinus under X-ray control in the left oblique projection. To obtain accurate diagnostic results in relation to myocardial ischemia, we used the bipolar recording system mode with the following settings: combining electrodes in five cathode-anode pairs with a frequency range of 1–10 Hz, a signal cut-off of 1 cm, and an amplitude of 0.3 mV/cm. The digital analysis of the obtained data was carried out using the EP WorkMate Recording System v.4.3.2 computer program.

Statistics

Statistical data processing was performed on an MSI personal computer using Microsoft Excel and the Statistica 10 data

analysis software for Windows (StatSoft Inc., USA). Statistical processing of the material provided to obtain combination tables, diagrams, graphs and analytical indicators were: structure (p), mean values (M) and standard deviations (\pm sd). Quantitative variables were described by the following statistics: number of patients, arithmetic mean (M), standard deviation from the arithmetic mean (δ), 25th and 75th percentiles, and median. Differences were considered statistically significant at an error level of $p < 0.05$, with a p value less than or equal to the specified level indicating the statistical significance of the result.

Results

During the study, we compared the sensitivity of intracardiac ECG from the coronary sinus and surface electrocardiography (sECG) in relation to myocardial ischemia during percutaneous interventions on the coronary arteries. Patients were divided into 3 groups: Group I consisted of 56 (35.7%) patients with isolated lesions of the anterior descending artery (ADA); group II included 50 (31.9%) patients with stenosing lesions of the left circumflex coronary artery (LCx); and group III consisted of 51 (31.8%) patients with atherosclerotic lesions of the right coronary artery (RCA).

All 157 (100%) patients were diagnosed with coronary artery disease based on clinical examination, factoring in an analysis of complaints, medical history and life data, objective research methods and stress tests.

According to clinical and anamnestic data, the patients of the three groups did not differ significantly (Table 1).

The right dominant CA prevailed — 133 (84.7%). The degree of stenosis and its length were $82 \pm 10.4\%$ and 8.8 ± 3.1 mm, respectively. In all groups, among the types of lesions, B1 and B2 prevailed: 67 (42.6%) and 59 (37.6%); type A was found in 22 patients (14.1%) and type C in 9 (5.7%), according to the ACC / ANA classification. The angiographic characteristics of patients are presented in table 1.

Significant criteria for ischemia according to ECG-CS were considered ST segment changes of more than 0.1 mV in 2 adjacent intracardiac leads, and according to the surface ECG — in standard and enhanced leads from the patient's extremities corresponding to the CA (I, II, aVL — LCA; II, III, aVF — RCA; I, aVL — LCx).

Immediately after insertion of the electrode into the coronary sinus, but before the introduction of instruments into the CA, no ischemic changes were detected in patients of any of the 3 groups by ECG-CS or sECG ($p > 0.05$).

Before stent placement, 31 (55.4%) patients with ADA lesions underwent predilation of the coronary artery stenosis zone with a balloon catheter. During balloon angioplasty (BA) in the PNA, ischemic changes ($p < 0.05$) were recorded on an ECG obtained using an intracardiac electrode. Depression of the ST segment was recorded in leads CS 1–2 and averaged 0.09 ± 0.02 mV, while in CS 3–4: 0.09 ± 0.05 mV. Elevation of the ST segment was recorded in leads CS 1–2 — 0.1 ± 0.04 mV, CS 3–4 — 0.1 ± 0.05 mV. A significant and simultaneous deviation of the ST segment from the isoline in two adjacent ECG-VS leads was recorded in 26 patients (83.9%) (Table 2).

Table 1. Clinical data and angiographic characteristics of patients

Criterion	Index	
Clinical and anamnestic data		
Criterion	Number of patients	
Number of patients	157 (100%)	
Men	122 (77,7%)	
Woman	35 (22,3%)	
Average age	58,3±2,2	
Functional class of angina	I	0
	II	92 (58,6%)
	III	65 (41,4%)
	IV	0
Arterial hypertension	102 (64,9%)	
Diabetes mellitus	32 (20,4%)	
History of ischemic stroke	5 (3,2%)	
Hyperlipidemia	109 (69,4%)	
Obesity	69 (43,9%)	
Smokers	74 (47,1%)	
Angiographic characteristics of patients		
Coronary artery dominance, n (%)	Right-dominant	133 (84,7%)
	Left-dominant	16 (10,2%)
	Co-dominant	8 (5,1%)
Coronary artery	ADA	56 (35,7%)
	LCx	50 (31,9%)
	RCA	51 (31,8%)
Degree of stenosis, %	82±10,4%	
Extent of lesion, mm	8,8±3,1	
Reference artery diameter, mm	3,2±0,4	
Lesion type ACC/AHA	Type A	22 (14,1%)
	Type B1	67 (42,6%)
	Type B2	59 (37,6%)
	Type C	9 (5,7%)
SYNTAX Score I	ADA	8,34±1,58
	LCx	4,87±1,91
	RCA	2,76±0,71

Table 2. ECG during ADA intervention

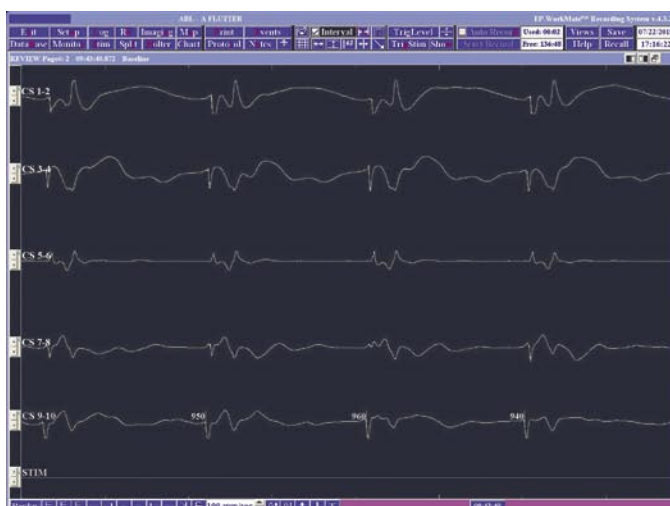
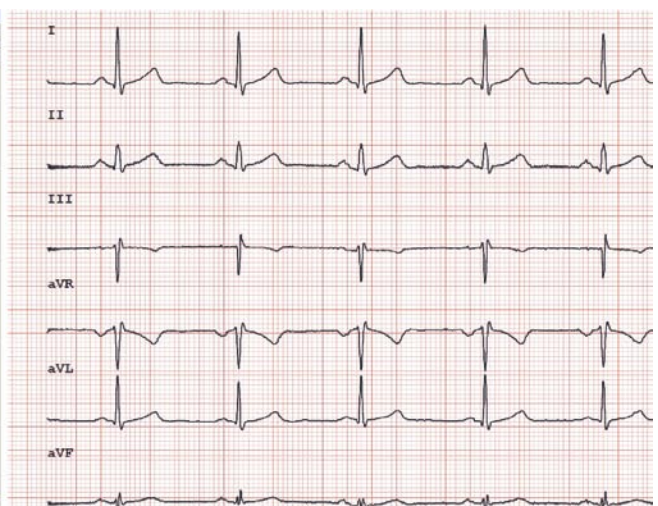
ST segment dynamics	Ballon angioplasty (n = 31)		Stent implantation (n = 56)	
	Depression	Elevation	Depression	Elevation
Surface ECG				
Lead				
I	0,07±0,03*	0,06±0,05*	0,1±0,01*	0,1±0,02*
II	0,06±0,03	0,04±0,02	0,08±0,01	0,07±0,01
III	0,05±0,04	0,03±0,01	0,07±0,02	0,06±0,01
aVR		0,01±0,01		0,03±0,03
aVL	0,05±0,04	0,03±0,01	0,07±0,02	0,06±0,02
aVF	0,03±0,01	0,02±0,01	0,08±0,01	0,1±0,02*
The frequency of registration of a significant deviation of the ST segment	32,3%		42,9%	
Intracardiac ECG				
Lead				
CS 1–2	0,09±0,02*	0,1±0,04*	0,11±0,02*	0,15±0,03*
CS 3–4	0,09±0,05*	0,1±0,05*	0,12±0,02*	0,11±0,02*
CS 5–6	0,05±0,02	0,07±0,03	0,05±0,02	0,04±0,03
CS 7–8	0,05±0,02	0,05±0,01	0,06±0,02	0,06±0,03
CS 9–10	0,07±0,01	0,05±0,01	0,04±0,05	0,07±0,04
The frequency of registration of a significant deviation of the ST segment	83,9%		91,1%	

* — p<0,05

Significant and simultaneous deviation of the ST segment by sECG in all three adjacent leads responsible for the ADA — I, II, aVL — during balloon angioplasty of the artery was recorded in 10 patients (32.3%).

Thus, the sensitivity in registering a reliable ischemic heart rate of an intracardiac ECG at this stage of PCI exceeded that in comparison with the standard ECG technique by 51.6%.

During coronary stenting (CS) ADA, ECG-CS revealed significant (p<0.05) depression of the ST segment in leads CS 1–2 (0.12±0.03 mV), and CS 3–4 (0.1±0.02 mV) (Fig. 1);

**Figure 1.** Stent implantation in ADA.

elevation: 0.14 ± 0.04 mV and 0.11 ± 0.02 mV, respectively. A significant deviation of the ST segment from the isoline in two adjacent ECG-VS leads was simultaneously recorded in 51 patients (91.1%).

Significant and simultaneous changes in the ST segment on the surface ECG on leads I, II, and aVL during ADA stenting were registered in 24 patients (48.2%) (Table 2).

Thus, when comparing the methods, the accuracy with respect to the verification of MyI when using ECG-CS during CS exceeded the sensitivity of pECG by 50%.

In group II (LCx), predilatation of the stenosis zone was performed in 33 (58.9%) patients. During intervention in the LCx (Table 3) during balloon inflation, ischemic changes ($p < 0.05$) were recorded on the ECG-CS. Depression of the ST segment was recorded in leads CS 3–4 — 0.08 ± 0.03 mV, and in CS 5–6 — 0.09 ± 0.04 mV. ST segment elevation was recorded in the same leads and averaged 0.1 ± 0.04 mV, and 0.12 ± 0.05 mV. Simultaneous registration of a significant deviation of the ST segment from the isoline in leads CS 3–4 and CS 5–6 was detected in 26 patients (78.8%).

According to the surface ECG, a significant and simultaneous deviation of the ST segment in leads I and aVL during balloon inflation of the LCx was detected in 8 patients (24.2%).

Thus, when comparing ischemic dynamics in the process of angioplasty LCx, the sensitivity of ECG-CS exceeded sECG by 54.6% in this parameter.

During the implantation of a coronary stent in the LCx, intracardiac ECG revealed depression of the ST segment in leads CS 3–4 — 0.11 ± 0.02 mV, and in CS 5–6 — 0.11 ± 0.02 mV; elevation — 0.12 ± 0.02 mV and 0.15 ± 0.03 mV ($p < 0.05$), respectively. At the same time, significant depression and elevation of the ST segment in the intracardiac leads CS 3–4 and CS 5–6 were detected in 31 patients (82%) (Table 3).

Significant and simultaneous ischemic changes in the ST segment on the surface ECG on leads I and aVL during LCx stenting were detected in 10 patients (20%) (Fig. 2).

Table 3. ECG during LCx intervention

ST segment dynamics	Ballon angioplasty (n = 33)		Stent implantation (n = 50)	
	Depression	Elevation	Depression	Elevation
Surface ECG				
Lead				
I	$0,07 \pm 0,02$	$0,06 \pm 0,03$	$0,06 \pm 0,03$	$0,05 \pm 0,04$
II	$0,04 \pm 0,01$	$0,04 \pm 0,01$	$0,04 \pm 0,02$	$0,03 \pm 0,01$
III	$0,03 \pm 0,02$	$0,02 \pm 0,01$	$0,03 \pm 0,01$	$0,02 \pm 0,01$
aVR	$0,04 \pm 0,01$	$0,05 \pm 0,02$	$0,03 \pm 0,02$	$0,02 \pm 0,01$
aVL	$0,07 \pm 0,03$	$0,07 \pm 0,02$	$0,07 \pm 0,01$	$0,05 \pm 0,03$
aVF	$0,03 \pm 0,01$	$0,04 \pm 0,01$	$0,03 \pm 0,01$	$0,04 \pm 0,01$
The frequency of registration of a significant deviation of the ST segment	24,2%		20%	
Intracardiac ECG				
Lead				
CS 1–2	$0,04 \pm 0,02$	$0,03 \pm 0,01$	$0,04 \pm 0,01$	$0,03 \pm 0,01$
CS 3–4	$0,08 \pm 0,03^*$	$0,1 \pm 0,04^*$	$0,11 \pm 0,01^*$	$0,12 \pm 0,03^*$
CS 5–6	$0,09 \pm 0,04^*$	$0,12 \pm 0,05^*$	$0,12 \pm 0,03^*$	$0,16 \pm 0,03^*$
CS 7–8	$0,03 \pm 0,01$	$0,05 \pm 0,03$	$0,05 \pm 0,04$	$0,07 \pm 0,01$
CS 9–10	$0,04 \pm 0,01$	$0,04 \pm 0,02$	$0,05 \pm 0,03$	$0,04 \pm 0,03$
The frequency of registration of a significant deviation of the ST segment	78,8%		82%	

* — $p < 0.05$.

When comparing the sensitivity of the methods in the process of stent implantation in the LCx, the accuracy of ECG-VS exceeded that of pECG by 62%.

In the course of intervention in the RCA (group III), in 28 cases (54.9%) before stent placement, patients underwent predilatation of the stenosis zone (Table 4). During balloon inflation, ischemic changes ($p < 0.05$) were recorded on the ECG-CS.

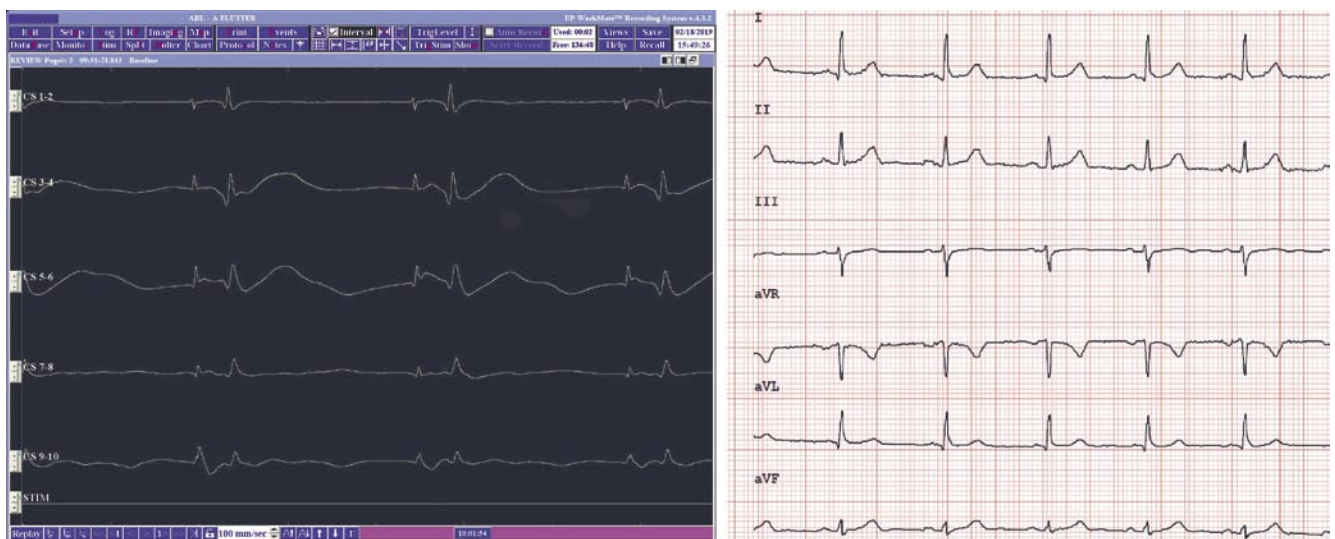


Figure 2. LCx stenting.

Table 4. ECG during RCA intervention

ST segment dynamics	Ballon angioplasty (n = 28)		Stent implantation (n = 50)	
	Depression	Elevation	Depression	Elevation
Surface ECG				
Lead				
I	0,04±0,02	0,03±0,02	0,04±0,02	0,03±0,03
II	0,06±0,03	0,05±0,02	0,06±0,02	0,05±0,03
III	0,06±0,04*	0,05±0,04	0,09±0,01*	0,07±0,03*
aVR	0,03±0,01	0,04±0,01	0,05±0,02	0,05±0,01
aVL	0,04±0,01	0,04±0,01	0,03±0,02	0,05±0,01
aVF	0,04±0,02	0,07±0,01	0,08±0,02*	0,07±0,03*
The frequency of registration of a significant deviation of the ST segment	35,7%		39,2%	
Intracardiac ECG				
Lead				
CS 1–2	0,06±0,02	0,05±0,01	0,04±0,01	0,03±0,01
CS 3–4	0,07±0,01	0,04±0,01	0,04±0,03	0,04±0,02
CS 5–6	0,05±0,03	0,03±0,01	0,06±0,01	0,06±0,02
CS 7–8	0,09±0,04*	0,12±0,03*	0,11±0,01*	0,13±0,02*
CS 9–10	0,14±0,05*	0,12±0,05*	0,13±0,03*	0,14±0,03*
The frequency of registration of a significant deviation of the ST segment	82,1%		86,3%	

* — $p < 0,05$.

ST segment depression was recorded in leads CS 7–8 and averaged 0.09 ± 0.04 mV, and in CS 9–10 — 0.14 ± 0.05 mV. ST segment elevation was recorded in the same leads: 0.12 ± 0.03 mV and 0.12 ± 0.05 mV, respectively. Significant depression and ST-segment elevation in intracardiac leads CS 7–8 and CS 9–10 were detected in 23 patients (82.1%).

Significant and simultaneous ischemic changes in the ST segment on the surface ECG on leads II, III, and aVF during

balloon inflation in the RCA were detected in 10 patients (35.7%).

During RCA inflation, the sensitivity of the ECG-CS method exceeded that of surface ECG by 46.4%.

During coronary stenting of the RCA, intracardiac ECG revealed depression of the ST segment in leads CS 7–8 — 0.1 ± 0.01 mV, and CS 9–10 — 0.12 ± 0.02 mV; elevation in CS 7–8 — 0.13 ± 0.02 mV, and in CS 9–10 — 0.14 ± 0.03 mV ($p < 0.05$), respectively (Fig. 3). Significant changes in the ST segment in the intracardiac leads CS 7–8 and CS 9–10 were detected in 44 patients (86.3%) (Table 4).

Significant ischemia, according to the data obtained with sECG, was registered simultaneously in leads II, III, and aVF during stent placement in the RCA in 20 patients (39.2%).

When comparing the sensitivity of the methods to MyI in the process of CS RCA, the intracardiac ECG surpassed the sECG by 47.1%.

Discussion

The evolution of electrophysiological monitoring of myocardial ischemia is, in its essence, associated with the prospect of overcoming the limiting factors of registering cardioelectric potential found only on the surface of the human body. The application of a new ECG method from the coronary sinus, proposed by academician Yu.L. Shevchenko and based on the unification of the existing standardized technique of invasive electrophysiological monitoring, allows doctors to obtain objective information on the dynamics of the ST segment at all stages of coronary stenting. The use of an intracardiac electrode makes it possible to register reliable changes in the ST segment in all basins of the CA.

When conducting a partial comparative analysis of the sensitivity of the surface ECG and the ECG-CS techniques, the ECG-CS method was shown to be significantly superior in its accuracy compared to the standard surface ECG with regard to verifying myocardial ischemia during endovascular interventions in various coronary arteries.

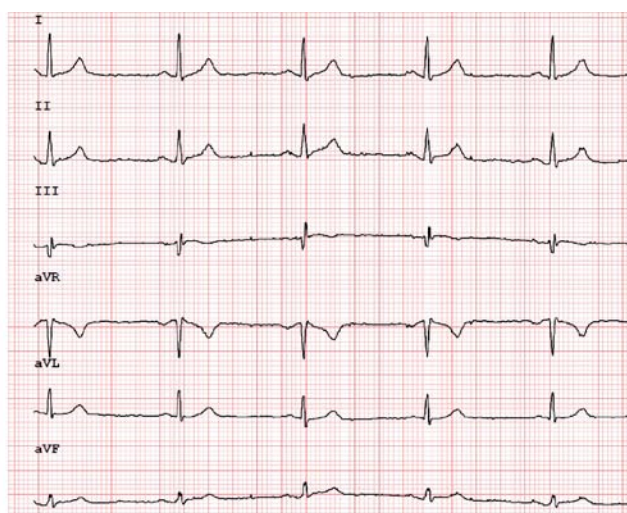
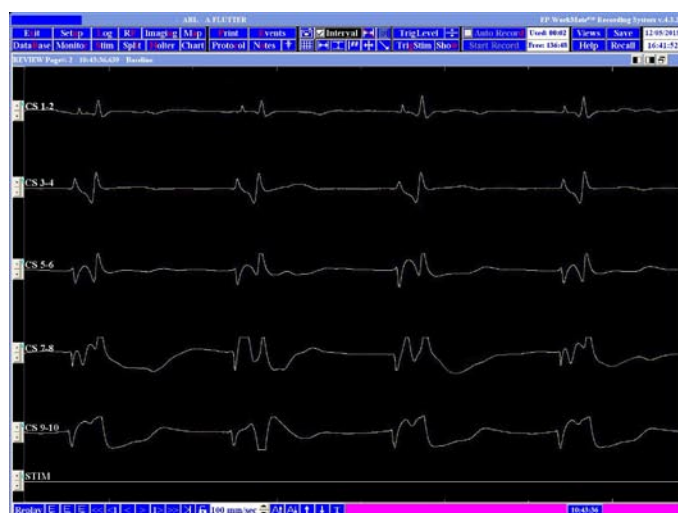


Figure 3. RCA stenting.

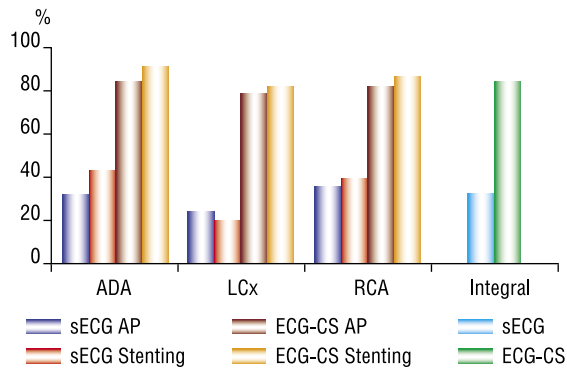


Figure 4. Dynamics of the ST segment during coronary intervention.

A higher sensitivity of ECG-CS during objectification of MyI was recorded during the implementation of balloon angioplasty of the ADA, LCx and RCA with simultaneous registration of significant ischemic changes in the complexes of critical leads sECG and ECG-CS with a frequency of 32.3%, 24.2% and 35.7% versus 83.9%, 78.8% and 82.1%, respectively.

In the process of stenting the ADA, LCx, and RCA coronary arteries, the sensitivity to myocardial ischemia of both diagnostic methods was 42.9%, 20% and 39.2% versus 91.1%, 82% and 86.3%, respectively. At the same time, the accuracy of the objectification of myocardial ischemia by analyzing the amplitudes of sECG in standard and enhanced leads without the use of chest electrodes remained ambiguous in the process of intervention on the LCx.

The integral sensitivity of the sECG and ECG-CS methods to MyI, without taking the stage of coronary intervention and the CA into account, was 32.4% and 84%, respectively (Fig. 4).

Conclusion

The technique of electrocardiography from the coronary sinus, proposed and implemented in practice by academician of the Russian Academy of Sciences Yu.L. Shevchenko, when used in comparison with the standard surface ECG, allows for a much higher accuracy determination of the degree and localization of myocardial ischemia during endovascular interventions on the coronary arteries.

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