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High Resolution Heart Rate Variability Analysis in Patients with Angina Pectoris during Coronary Artery Bypass Graft Surgery

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Abstract. The purpose of the study is approbation of the capabilities of high-resolution rhythmocardiography (RCG) for the determination of the actual cardiovascular status of operated patients with angina pectoris during coronary artery bypass graft surgery (CABGS) for myocardial revascularization. The research was done by means of a KAP-RK-02-Mikor hardware-software complex with a monitor record and the time- and frequency-domain analyses of heart rate variability (HRV). Monitor records were made at each stage of CABGS in 123 patients. As a result, HRV manifested itself as a fairly adequate and promising method for the determination of the cardiovascular status during CABGS. In addition, the data of the HRV study during CABGS testify to the capability of RCG to determine the high risk of life-threatening cardioarrhythmias before and during operation, to different changes in sinoatrial heart node (SN) dysregulation, and contain the HRV symptoms of a high death risk before, during and after shunting. The loss of the peripheral autonomic sympathetic and parasympathetic control in SN in the form of the autonomic cardioneuropathy syndrome is a predictor of the complications related to CABGS. The obtained data on RCG monitoring of HRV recording are suggestive of wide prospects of the high-resolution RCG method to be used in cardiac surgery as a whole. The actual multivariant dysregulations of SN pacemaker activity testify to its adequacy to the pathophysiology of each period of the cardiac operation, according to the initial ischemic damages and localization of cardiosurgical manipulations during CABGS.

INTRODUCTION

The purpose of the research is estimation of the capabilities of the high-resolution rhythmocardiography (RCG) for heart rate variability (HRV) recording and analysis in order to determine the actual cardiovascular status in the patients with stable stenocardia before, during and after coronary artery bypass graft surgery (CABGS). This purpose is achieved through the assumption that cardiac surgery, as well as cardiology as a whole, have no [1, 2, 15, 13] informative and noninvasive method for the determination of sinoatrial heart node (SN) dysregulations, which may be useful for early diagnostics of cardiovascular pathology. A high-resolution RCG

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method has been developed to analyze the activity of an SN pacemaker and its dysregulation. Besides, a KAP-RK-01-(02)-Mikor hardware and software complex (HSC) has been developed as equipment for it. The HRV analysis was useful in the actual diagnosis of a cardiovascular status before, after and intraoperatively under CABGS. Earlier studies on this subject had no convincing results [1, 2, 10, 12]. The RCG, the HSC and the analysis of HRV were approbated with positive results of CABGS. It is supposed that innovative clinical achievements in the HRV registration and analysis are important for the identification of predictors and markers of CABGS complications [3, 4, 6], including life-threatening arrhythmias [7, 8, 9, 11].

MATERIALS AND METHODS

Initially, 256 patients (pts) with coronary artery disease (CAD) were investigated by standard cardiological methods and by RCG with HRV analyses in time and frequency domains with the use of the fast Fourier transformation and Parzen's and Hamming's spectral windows. 47 healthy men (fig. 1) were investigated that way for control. After the initial investigation before CABGS, 123 pts were chosen for shunting, and 133 pts were sent for stenting. Initially, additional RCG symptoms characteristic for stable angina pectoris were defined for all the pts (fig. 2).

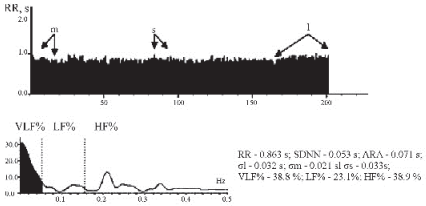

FIGURE 1. A rhythmocardiogram, a spectrogram and middle values of the RCG indices of a healthy man. σl is the middle quadratic deviation of humoral HRV waves, σm is the middle quadratic deviation of sympathetic HRV waves, σs is the middle quadratic deviation of parasympathetic HRV waves. The spectral correlation of autonomic and humoral-metabolic influences in the sinoatrial heart node is as follows: VLF% is the share of humoral-metabolic regulation, LF% is the share of sympathetic regulation, HF% is the share of parasympathetic regulation in the whole spectrum (100%)

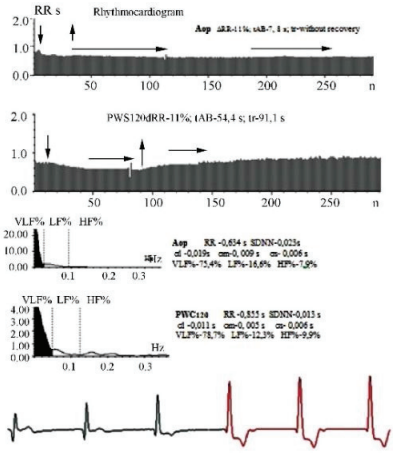

FIGURE 2. Rhythmocardiograms, spectrogram and the middle values of the HRV indices for a patient with a stable angina pectoris 2 FC in Aop and PWC 120 tests. The amplitudes of HRV waves are reduced. The spectrograms show the pathologically changed spectral shares of the influence of the regulation factors in SN with sympathetic and parasympathetic oppression of the regulation of the pacemaker activity and a significant increase in the humoral-methabolic influence in SN, physiologically inadequate and insufficient. The reaction to passage in Aop is reduced (ΔRR), the time of its achievement and the restoration time (tAB, tr) increase. The vertical arrows denote the beginning and the end of the stimuli period in the test. The horizontal arrows show ischemic episodes of HRV stabilization in patients with angina pectoris, which was accompanied by the depression of ST.

123 pts underwent CABGS on an open heart being stopped and connected to an artificial blood-circulation apparatus (ABC) with the use of a cardiopulmonary pump. During CABGS, HRV was recorded by the monitor of the KAP-RK-02-Mikor hardware and software complex. Basic average HRV indices were RR (the average level of all the intervals), SDNN (their standard deviation), the average square deviations of the humoral-metabolic (σl), sympathetic (σm) and parasympathetic (σs) amplitudes of HRV-waves. The spectral analysis was calculated to define the correlation of regulatory factors in the SN – humoral-metabolic (VLF%), sympathetic (LF%) and parasympathetic (HF%) shares (fig. 1). Rhythmocardiograms (RCG) were sent to the laboratory of neurocardiology for immediate analysis and recommendations. HRV was recorded before and after a cardiac arrest and passage to the ABC. At the moments of the work of the electric knife, the HRV recording was stopped. RCG and ECG were recorded in real (current) time. Fragments of RCG records of 300 RR intervals were automatically collected in the file with the computer analysis, the ECG being saved in the archive with a resolution of 1 ms. The HRV results could be displayed on the monitor with a synchronous ECG record. HRV before and after CABGS was studied at rest, and 4 directed tests were performed. RCG was a graphic image of intersystole pauses between heart contractions in the form of vertical rectilinear pieces with equal duration of RR intervals, beginning on the abscissa and continuing parallel to the ordinate axes (figs. 1 to 4). Statistical evaluation of the computer material was made by the Statistica10 special program. Student's t-, z- and p-tests were used. The norm of the distribution was checked with N. Kolmogorov and Yu. Tyurin. The nonparametric Spearman method was applied to analyze the correlation between the HRV data and the data of standard investigations using the SPSS 12.0 program.

RESULTS AND INTERPRETATION

Initially, in the primary RCG examination before CABGS, HRV reduction adequate to CAD expression [1, 2 and 14] for all the pts selected for the cardiosurgical myocardial revascularization was defined. Except HRV reduction, there were HRV fragments looking as HRV stabilization without any wave structure on the RCG under conditions of the modern sensitivity of computer monitors. The difference between neighboring RR intervals ranged within 3.55±1.02 ms (fig. 2). These fragments correlated with the duration of the clinical and ECG symptoms of the ischemic episodes. They were connected to the hibernation of the SN pacemaker cells during myocardial perfusion disturbance due to a critical occlusion of 70-80% of the SN arteria (Patent No. 2322942).

The stages registered during shunting had their own HRV wave structure related to the peculiarities of every CABGS period. After premedication and intubation narcosis, when a cardioplegic solution was introduced before the passage of heart contractions to ABC, all HRV waves disappeared, and the heart gradually stopped. However, before that, the direct surgical manipulations on the heart tissues were accompanied by different cardiac arrhythmias, namely, ventricular extrasystoles, parasystoles, bigeminy till asystole and others. Every clinical form of arrhythmia corresponded to the localization of surgical manipulations, i.e. atrial arrhythmias, including atrial fibrillation registered during the cannulation of the right atrium, ventricular arrhythmias appearing during cannulation and installation of clips in the aorta and also during the direct heart massage after the ABC cut off.

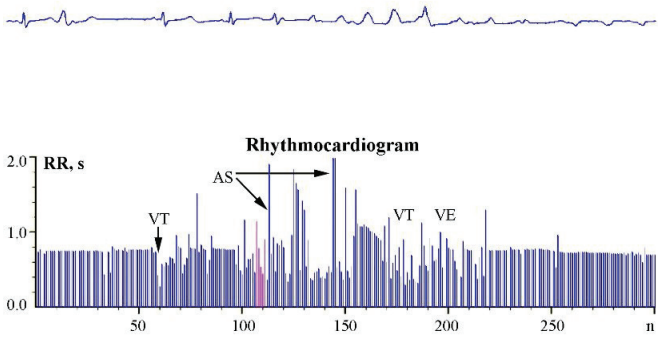

FIGURE 3. RCG and ECG at clip installation in the aorta. At clip installation in the aorta and the introduction of a cardioplegic solution, blood ceased entering the aorta from the left heart ventricle. Simultaneously, the blood entered from the apparatus of artificial circulation. Surgical manipulations with heart ventricles caused cardio arrhythmias in the form of a number of polyfocal ventricular extrasystoles (VE) and the replaceable rhythms, episodes of the ventricular tachycardia (VT), asystolia (AS).

Before CABGS there were 56 pts with autonomic cardioneuropathy (ACN) with evident rhythm stabilization. ACN was defined as the most significant preoperative marker of life-threatening complications after CABGS. Also, there was the largest spectral share of humoral-metabolic influence on the SN, the time of reactions to tests and restoration being maximal.

TABLE 1. The average HRV indices during the CABGS stages (n-123)

Average HRV indices (M±σ), s and %, cardiac arrhythmias	RR, s, average RR interval	SDNN, s, average quadratic deviation of all HRV waves	σl, s, average quadratic deviation of humoral HRV waves	σm, s, average quadratic deviation of symp. HRV waves	σs, s, average quadratic deviation of parasymp. HRV waves	VLF%, spectral share of humoral HRV waves	LF%, spectral share of symp. HRV waves	HF%, spectral share of parasymp. HRV waves
Intubation and narcosis	0.783 ± 0.03	0.003 ± 0.001	0.003 ± 0.001	0.001 ± 0.001	0.001 ± 0.001	72.2 ± 18.4%	12.8 ± 4.2%	15.0 ± 3.5%
Cannulation, AF, ventr. arrhythmias	0.653 ± 0.024	0.003 ± 0.001	0.003 ± 0.001	0.001 ± 0.001	0.001 ± 0.001	84.2 ± 11.2%	7.4 ± 3.4%	8.4 ± 2.8%
Introduction of CPS, AF, ventr. arrhythmias, asystolia	0.810 ± 0.033	0.004 ± 0.001	0.002 ± 0.002	0.004 ± 0.001	0.001 ± 0.001	91.2 ± 7.2%	6.4 ± 2.3%	2.4 ± 1.9%
Connection to artificial circulation	0.580 ± 0.087	0.002 ± 0.001	0.002 ± 0.002	0.002 ± 0.001	0.001 ± 0.001	90.2 ± 10.8%	6.8 ± 3.2%	3.0 ± 1.9%
Removal clips, heart restoration, heart arrhytmias	0.564 ± 0.034	0.003 ± 0.001	0.003 ± 0.001	0.002 ± 0.001	0.001 ± 0.001	88.6 ± 12.4%	5.4 ± 1.9%	5.0 ± 2.1%
Heart restoration	0.680 ± 0.110	0.006 ± 0.002	0.006 ± 0.002	0.002 ± 0.001	0.001 ± 0.001	87.2 ± 7.12%	5.0 ± 2.1%	7.8 ±3.4%

The table presents data of statistic and spectral analyses of HRV indices at different CABS stages. After intubation narcosis, HRV indices are very low. The initially low HRV indices before operation became totally even lower during narcosis in the units of milliseconds. The highest amplitude belonged to the humoral-metabolic HRV waves (σl), although it was low too. At the spectral correlation of the shares of the regulative factors in the SN, the influence of the humoral-metabolic environment on the SN (VLF%) was predominant over autonomic sympathetic (LF%) and parasympathetic (HF%) influences during all the CABGS stages.

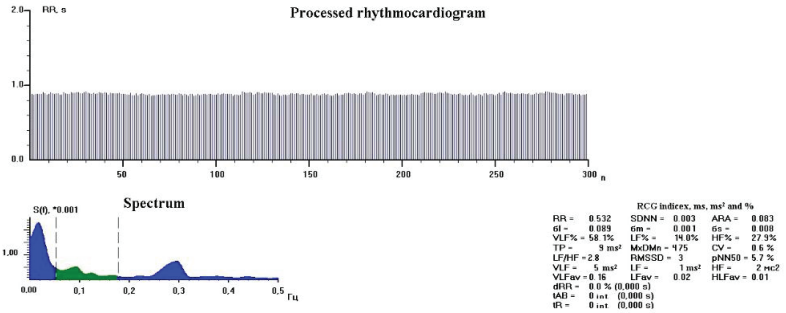

FIGURE 4. RCG, spectrogram and HRV indices of a patient with CAD and ACN with HRV stabilization, values of σl, σm and σs are respectively 2, 1 and 2 milliseconds only, and the biggest humoral influence on the SN is 58.1%.

This group of pts was the most clinically serious. The HRV of the pts with ACN testified to the absence of the autonomic control in the SN. One pt with CAN died in 4 days. On the background there were episodes of atrial fibrillation, the migration of rhythm pacemaker and the SN dysfunction.

CONCLUSION

1. RCG with high resolution is an adequate and promising method of the evaluation of the actual cardiovascular status before, during and after cardiosurgical myocardial revascularization for patients with angina pectoris.

2. The HRV analysis in the time and frequency domain consists of symptoms for intranosological diagnostics in the selection of patients for the CABGS treatment of stenocardia, and it consists mainly of HRV symptoms of the high risk of life-threatening complications during operation, including cardiac arrhythmias.

3. The HRV research results testify to the possibilities of determining a high risk of arrhythmias and also the lethal outcome at CABGS. The loss of peripheral autonomic sympathetic and parasympathetic control in the sinoatrial node, as syndrome of autonomic cardioneuropathy, is a predictor of complications at a cardiosurgical operation.

4. The obtained data on numerous variants of dysregulations of the sinus node pacemaker activity in the heart are physiologically adequate to the stages of a cardiosurgical operation, connected with ischemic breaches of the CAD, as soon as the breaches are connected with the localization of the cardiosurgical manipulations during CABGS.

5. It has been proved that CAD is certain to be accompanied by the dysregulations of the SN pacemaker activity. Its dynamics corresponds to the actual cardiovascular status of patients, and it can be used at a number of cardiological diseases and for their cardiosurgical treatment.

REFERENCES

1. T. Mironova, V. Mironov, *Heart Rate Variability in the Coronary Artery Disease,* 2nd ed. (Rekpol, Chelyabinsk, 2008).
2. A. Teplakov, A. Lukinov, J. Clinical Medicine **3**, 21–26 (2010).
3. R. M. Carney, J. A. Blumenthal, Arch. Intern. Med. **165**, 1486–1491 (2005).
4. T. K. Dao, N. A. Youssef, J. Cardiothorac. Surg. **13** (5), 36 (2010).
5. "Guidelines on myocardial revascularization", in Eur. Heart J. **31**, 2501–2555 (2010).
6. J. M. Kalisnik, V. Avbelj, Heart Surg. Forum **10 (**4), E 279–287 (2007).
7. B. Kazemi, A. Ahmadzadeh, Eur. J. Cardiothorac. Surg. **40** (5), 1191–1196 (2011).
8. J. Ksela, J.. Kalisnik, Wien Klin, Wochenschr **121** (9–10), 324–329 (2009).
9. T. Laitio, J. Jalonen, Anesth. Analg. **105** (6), 1548–1560 (2007).
10. H. Lakusic, B. Slivnjak, Cardiology Research and Practice (2009). doi:10.4061/2009/295376.
11. S. Y. Min, D. W. Park, Circ. Cardiovasc. Interv. **3**, 127–133 (2010).
12. T. Mironova, V. Mironov, *Clinical Analysis of Heart Rate Variability* (Zauralye Publisher, Kurgan, 2000)
13. T. Mironova, M. Bavykin, "HRV-analysis in patients with ischemic cardioarrhythmias", in Annales of Arrhythmology, Proceedings of the Fourth All Russian Congress of Arrhythmologists, Moscow, June 16–18, 2011 (Moscow, 2011), Vol. 2, p. 21.