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Characteristics of left ventricular and cardiac hemodynamic remodeling after on-pump or off-pump coronary artery bypass grafting

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ABSTRACT

Aim. To study the comparative dynamics of left ventricular (LV) remodeling after on-pump and off-pump coronary artery bypass grafting.

Materials and methods. The study included 129 patients with verified coronary artery disease (CAD) who underwent coronary artery bypass grafting (CABG) with cardiopulmonary bypass (on-pump CABF) or beating heart surgery (off-pump CABG). All patients underwent transthoracic echocardiography (TTE) and volumetric compression oscillometry (VCO) before surgery, as well as one week and four months after it. The results were compared in groups divided according to the surgical technique and the presence of previous myocardial infarction using variation series, the Tukey's post-hoc test, the Pearson correlation coefficient, and the Spearman's rank correlation coefficient.

Results. According to TTE data, no difference in hemodynamic parameters between the groups in the postoperative period was noted. According to VCO data, a significant difference was revealed in the off-pump group without previous MI one week after surgery: an increase in cardiac output (CO) ($p < 0.001$), an increase in stroke volume (SV) and stroke index (SI) ($p = 0.005$), LV power (LVP) ($p = 0.015$), and also a rise in cardiac index and LVP four months after the surgery. In the on-pump group of patients with previous MI a week after CABG, a decrease in the LVP ($p < 0.001$) and dynamic changes of energy expenditure ($p < 0.001$) were observed. The correlation analysis revealed moderate correlations between the inotropic parameters of cardiac hemodynamics SV, SI, CO, LVP and blood pressure (BP) ($r\pi = 0.33–0.47$; $p < 0.001$) and strong correlations between SV, SI, CO, LVP and ejection fraction (EF) ($r\pi = 0.63–0.68$; $p < 0.001$).

Conclusion. Seven days after the off-pump CABG, an improvement in some hemodynamic parameters and all inotropic parameters of the heart was revealed compared with the on-pump group. Four months after the off-pump surgery, positive hemodynamic remodeling was observed compared with the postoperative period after the on-pump CABG.

Keywords: coronary artery bypass grafting, off-pump surgery, remodeling

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Особенности ремоделирования миокарда левого желудочка и сердечной гемодинамики после коронарного шунтирования on-pump или off-pump

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РЕЗЮМЕ

Цель исследования. Изучить сравнительную динамику ремоделирования левого желудочка (ЛЖ) после операций коронарного шунтирования (КШ) с использованием методов искусственного кровообращения (ИК) и на бьющемся сердце.

Материалы и методы. В исследование включены 129 пациентов с верифицированной ишемической болезнью сердца (ИБС), которым было выполнено КШ в условиях ИК (on-pump) или на бьющемся сердце (off-pump). Всем пациентам перед операцией, через 1 нед и через 4 мес проводилась эхокардиография (ЭХОКГ) и объемная компрессионная осциллометрия (ОКО), результаты которых сравнивались в группах, разделенных по методике операции и в зависимости от наличия перенесенного инфаркта миокарда с использованием вариационных рядов, апостериорного критерия Тьюки, коэффициента Пирсона и коэффициента Спирмена.

Результаты. По данным ЭХОКГ не выявлено разницы гемодинамических показателей в группах сравнения в постоперационном периоде. По данным ОКО в группе «off-pump без постинфарктного кардиосклероза (ПИКС)» через 1 нед после операции отмечены статистические отличия следующих показателей: увеличение сердечного выброса (СВ) ($p < 0,001$), ударный объем (УО) и ударный индекс (УИ) ($p = 0,005$), мощность ЛЖ (МЛЖ) ($p = 0,015$), а также увеличение сердечного индекса и МЛЖ через 4 мес. В группе пациентов с ПИКС и on-pump через 1 нед после КШ наблюдалось снижение показателей МЛЖ ($p < 0,001$) и динамики расхода энергии ($p < 0,001$). При проведении корреляционного анализа были получены умеренные связи между инотропными параметрами сердечной гемодинамики УО, УИ, СВ, МЛЖ и артериального давления ($r\pi = 0,33–0,47$; $p < 0,001$) и заметные связи между УО, УИ, СВ, МЛЖ и фракцией выброса ($r\pi = 0,63–0,68$; $p < 0,001$).

Заключение. После операции КШ, выполненной off-pump, через 7 сут отмечено улучшение некоторых гемодинамических показателей и всех показателей инотропной функции сердца по сравнению с пациентами

on-pump. К 4-му мес после операции off-pump наблюдалось положительное гемодинамическое ре-ремоделирование по сравнению с послеоперационным периодом после on-pump.

Ключевые слова: коронарное шунтирование, off-pump, ремоделирование

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INTRODUCTION

In recent years, mortality from cardiovascular diseases (CVD) has been steadily decreasing thanks to the mass introduction of interventional methods of treatment and diagnosis of coronary heart disease (CHD) into clinical practice. Nevertheless, coronary artery bypass grafting (CABG) is still the surgery of choice in case of widespread multivessel atherosclerotic lesions of the coronary arteries (CA) with significant calcification, proximal stenosis of the left CA, as well as in patients with diabetes mellitus (DM) [1–3]. In such a group of patients, a successfully performed open heart surgery and direct myocardial revascularization lead to an improvement in the clinical condition, an improved functional class of angina pectoris, and an increase in the left ventricular ejection fraction (LVEF) [4, 5].

CABG can be performed both with the aid of cardiopulmonary bypass (CPB) and pharmacological cold crystalloid cardioplegia (PCCC) (on-pump CABG) and on a beating heart (off-pump CABG) [6–8]. During a surgery with the use of extracorporeal circulation, the heart undergoes ischemia and cardioplegia with further reperfusion. In this case, a condition known as stunned myocardium occurs, which causes a delay in the restoration of LV contractile function.

Direct myocardial revascularization on a beating heart (off-pump CABG) was developed to avoid reperfusion complications, increase the effectiveness of surgical treatment, and reduce postoperative mortality. The advantages of this approach include the absence of traumatic damage to blood cells, shorter surgery duration, and the absence of complications associated with CPB [9, 10].

However, there are still insufficient data in the modern literature on differences in remodeling of the heart and blood vessels in patients with CHD who underwent on-pump and off-pump direct revascularization. Such data are extremely important, since they would allow to plan postoperative rehabilitation of patients, taking into account the structural and functional remodeling of the LV of the heart, namely changes in the mass of the myocardium, the heart chambers, heart anatomy, its systolic and diastolic function, EF, etc.

The aim of this study was to conduct a comparative study of the changes in LV remodeling in patients with CHD after on-pump and off-pump surgical myocardial revascularization to optimize postoperative rehabilitation.

MATERIALS AND METHODS

The study included 129 patients with CHD aged 39–76 years (mean age 57.2 ± 8.6 years) with severe stenotic changes in CA, confirmed by coronary angiography (CAG), with different systolic LV function, who were scheduled for CABG.

The exclusion criteria from the study were considered to be acute coronary syndrome (ACS), acute cerebrovascular accident (ACA), cooccurring valvular pathology requiring surgical intervention; aneurysm of the aorta and LV, conditions after pacemaker implantation, as well as cancer, acute inflammatory, broncho-obstructive, rheumatic, endocrine, and infectious diseases. All patients underwent coronary artery or mammary artery bypass grafting with the placement of one, two (36.1%), and more than three shunts (63.9%).

All the examined patients were divided into four groups: group 1 – patients with postinfarction car-

diosclerosis (PICS), who underwent on-pump CABG with the aid of CPB (n = 47); group 2 – patients without PICS, who underwent on-pump CABG (n = 27); group 3 – patients with PICS, who underwent off-pump CABG (n = 28); group 4 – patients without PICS who underwent off-pump CABG (n = 27). CHD was confirmed by CAG. Comparative characteristics of patients by gender, age, presence of risk factors for CVD and concomitant diseases in the groups are presented in Table 1.

Table 1

Comparative characteristics of patients in groups, *n* (%)

Parameter	Group 1, n = 47	Group 2, n = 27	Group 3, n = 28	Group 4, n = 27
Average age, years, $M \pm SD$	60.5 ± 1.0	61.3 ± 1.2	57.6 ± 2.2	64.8 ± 2.8
Men	37 (78.7)	19 (70.3)	10 (35.7)	13 (48.1)
BMI, kg / m^2 $M \pm SD$	29.4 ± 4.7	27.8 ± 4.3	28.9 ± 4.1	29.2 ± 4.7
Smoking	25 (53.2)	14 (51.8)	10 (35.7)	14 (51.8)
EH	25 (53.2)	22 (81.5)	10 (35.7)	13 (48.1)
One damaged CA	12 (25.5)	10 (37.0)	8 (28.6)	10 (37.0)
≥2 damaged CAs	31 (65.9)	17 (62.9)	6 (21.4)	6 (22.2)
Left coronary main trunk stenosis	4 (8.5)	–	–	–
Diabetes mellitus	14 (29.8)	6 (22.2)	2 (7.1)	4 (14.8)
CABG (1–2 shunts)	14 (29.8)	15 (55.5)	10 (35.7)	10 (37.0)
CABG (≤3 shunts)	33 (70.2)	12 (44.4)	4 (14.3)	6 (22.2)

Note: EH – essential hypertension, BMI – body mass index, LCA – left coronary artery.

Transthoracic echocardiography (TTE) and volumetric compression oscillometry (VCO) were performed three times: before CABG, as well as7 days and 4 months after the surgery to assess remodeling and hemodynamics of the heart. The study was conducted with patients receiving standard drug therapy for CHD and chronic heart failure (CHF).

TTE was performed using Vivid 7 Dimension Pro, a high-performance ultrasound system. TTE was carried out immediately before the surgery, as well as 7 days and 4 months after CABG. The following parameters were evaluated during TTE: the LV end-diastolic diameter (EDD), the LV end-diastolic volume (EDV), the LV end-systolic volume (ESV), LVEF (using the Simpson's method), the interventricular septal thickness at end-diastole (IST), the left ventricular posterior diastolic wall thickness (LVPDWT), and the left atrial volume. The geometric remodeling of LV was evaluated by calculating indices for relative wall thickness (RWT), EDV, LV myocardial mass (LVMM), and left atrial volume (LAV).

VCO was performed using the APCO-8-RIC blood circulation parameter analyzer (Setal company, Kazan) [11]. This method is based on estimating changes in the volume of large arteries using an original measuring system. The examination method consists in automatic injection of air into the cuff at a controlled speed and simultaneous observation of oscillations on the monitor until the compression threshold and subsequent automatic decompression are reached. Patients undergoing this examination should be in the sitting position. They should fast prior to examination. The cuff is adjusted for every patient. Then, using the device software, the following hemodynamic parameters were calculated: cardiac output (CO); cardiac index (CI); stroke volume (SV); stroke index (SI); left ventricular power (LVP) (the product of SV and mean hemodynamic pressure); left ventricular ejection time (LVET) – the time interval from aortic valve opening to aortic valve closure and the phase of systole during which the left ventricle ejects blood into the aorta; volumetric flow rate (VFR) – the volume of blood being pumped by a single ventricle of the heart per one minute; energy for the displacement of one liter of blood (EDB). The values of the LV contractility, CO per minute, and the total ejection time per one minute allow to determine the energy spent for displacement of one liter of blood through the LV per one minute.

A statistical analysis was carried out using the IBM SPSS Statistics 20 software, which was used for the parametric and nonparametric analysis. Testing the compared aggregates for normality of distribution was evaluated by the Mann – Whitney – Wilcoxon test. The Fischer's exact test was used to study qualitative characteristics. The differences between the groups were considered statistically significant at

$p < 0.05$. When statistically significant differences were found between the groups, a pairwise comparison of aggregates was performed using the Tukey's post hoc test. Paired correlations were assessed by the Pearson's correlation coefficient (rπ) for interval variables and by the Spearman's rank correlation coefficient for ordinary values. The data were presented as absolute and relative values of *n (%)* and as the mean and the standard deviation $M \pm SD$.

RESULTS

The analysis of myocardial remodeling parameters according to the TTE data, depending on the presence or absence of PICS, is presented in Table 2.

Table 2

Changes in myocardial remodeling parameters according to the TTE data depending on the surgery type and the presence of PICS, *M ± SD*

Parameter	Period	Group 1, *n* = 47	Group 2, *n* = 27	Group 3, *n* = 28	Group 4, *n* = 27
LVMM	Before CABG,	239.5 ± 11.5	178.8 ± 7.0	220.8 ± 20.4	188.6 ± 6.2
	7 days after and	219.0 ± 11.0*	163.1 ± 8.8*	193.5 ± 14.5*	170.3 ± 5.7**
	4 months after the surgery	195.5 ± 9.3###	152.1 ± 5.3###	167.1 ± 10.8##	151.7 ± 5.4###
IST, cm	Before CABG,	1.10 ± 0.04	1.10 ± 0.04	1.15 ± 0.07	1.14 ± 0.05
	7 days after	1.06 ± 0.04*	1.07 ± 0.03*	1.10 ± 0.06	1.09 ± 0.05
	and 4 months after the surgery	1.0 ± 0.03###	1.02 ± 0.02###	1.02 ± 0.05#	1.01 ± 0.03###
LVPW, cm	Before CABG,	0.99 ± 0.04	1.0 ± 0.02	1.06 ± 0.06	1.01 ± 0.04
	7 days after	0.99 ± 0.03	1.0 ± 0.02	0.98 ± 0.05	1.01 ± 0.03
	and 4 months after the surgery	0.93 ± 0.02#	0.98 ± 0.02	0.95 ± 0.03#	0.96 ± 0.02##
LVRWT	Before CABG,	0.37 ± 0.02•	0.41 ± 0.01	0.43 ± 0.02	0.44 ± 0.02
	7 days after	0.36 ± 0.01	0.41 ± 0.02	0.39 ± 0.02*	0.41 ± 0.01
	and 4 months after the surgery	0.34 ± 0.01###	0.40 ± 0.01##	0.36 ± 0.02#	0.39 ± 0.01#
LVEDV, ml	Before CABG,	133.5 ± 8.8	82.4 ± 4.1	102.8 ± 8.2	78.8 ± 3.5
	7 days after	113.2 ± 6.6***	73.9 ± 3.6***	92.1 ± 8.7**	69.5 ± 3.4**
	and 4 months after the surgery	104.2 ± 5.3###	71.3 ± 3.0###	85.3 ± 6.2###	63.9 ± 2.6##
LAV, ml	Before CABG,	72.9 ± 3.8	58.3 ± 2.3	85.0 ± 9.2	60.4 ± 2.8
	7 days after	66.8 ± 3.4***	54.5 ± 2.2***	75.1 ± 6.8*	56.7 ± 2.6***
	and 4 months after the surgery	64.4 ± 2.6###	52.1 ± 1.9###	57.3 ± 4.2#	52.5 ± 2.5###
EF, %	Before CABG,	45.0 ± 1.4•	58.7 ± 0.7	52.5 ± 2.0	60.7 ± 0.9
	7 days after	44.7 ± 1.5	57.0 ± 0.7	50.5 ± 1.7	58.7 ± 1.3
	and 4 months after the surgery	48.5 ± 1.6##	61.9 ± 0.8	54.4 ± 1.8	61.8 ± 1.0

Note: LVPW – left ventricular posterior wall; LVEDV – left ventricular end-diastolic volume; LVMM – LV myocardial mass; ISP – interventricular septum; RWT – relative LV wall thickness; LAV – left atrial volume; EF – ejection fraction.

• statistical differences between the baseline parameters in groups 1 and 3: LVRWT $p = 0.023$; EF $p = 0.009$; statistical differences between the groups in baseline parameters and on day 7 after CABG: * $p < 0.05$; ** $p < 0.005$; $p < 0.001$***; statistical differences between the groups in baseline parameters and 4 months after CABG: # $p < 0.05$; ## $p < 0.005$ ### $p < 0.001$.

When assessing the differences in baseline TTE parameters between the groups of patients, we obtained statistically significant data on only two parameters – RWT and LVEF. Thus, in patients with a history of MI who underwent off-pump CABG (group 3), the thickness of the LV wall was less than in the group of patients who underwent on-pump surgery (group 1), while the EF was slightly higher. However, the differences in these parameters between the groups in the postoperative period were insignificant.

During the follow-up period, in all groups of patients, regardless of the presence of PICS and the type of surgery, a significant decrease in LVMM was observed as early as one week after CABG and especially by the 4th month postoperatively (Table 2). At the same time, the LV mass decreased evenly in all groups, regardless of the type of CABG. Changes in LVRWT compared to the baseline level became statistically significant only 4 months after the surgery. LVED and LAV decreased as early as one week after the surgery, and an even more pronounced decrease was observed after 4 months. The changes in EF in the early postoperative period were insignificant. However, 4 months after CABG, a statistically significant increase in this parameter was observed in the group of patients with PICS operated with the use of CPB and PCCC – from 45.0 ± 1.4 to 48.5 ± 1.6% ($p = 0.004$), which was probably due to the fact that myocardial contractility was initially lower in this group. The parameters of cardiac hemodynamics obtained using VCO are presented in Table 3.

Table 3

Hemodynamic parameters at baseline, 7 days after, and 4 months after the surgery in patients who underwent CABG, *M* ± *SD*

Parameter	Group 1, *n* = 47	Group 2, *n* = 27	Group 3, *n* = 28	Group 4, *n* = 27
CO, l / min				
Before CABG;	5.1 ± 0.1	5.2 ± 0.2	5.6 ± 0.3	4.8 ± 0.2
after 7 days;	4.9 ± 0.2	5.1 ± 0.2	5.5 ± 0.3	5.5 ± 0.2*
after 4 months	5.4 ± 0.2●	6.1 ± 0.3**	6.1 ± 0.3●	6.5 ± 0.2**
SV, ml:				
Before CABG;	83.1 ± 2.7	79.9 ± 3.7	92.9 ± 5.2	78.6 ± 5.5
after 7 days;	63.2 ± 2.7*	66.1 ± 3.8*	84.1 ± 6.9	85.8 ± 4.7*
after 4 months	79.4 ± 2.8	87.6 ± 4.3**	90.3 ± 6.4	97.2 ± 5.5**
SI, l / m^2:				
Before CABG;	42.4 ± 1.5	43.7 ± 1.8	48.2 ± 3.2	43.0 ± 2.7
after 7 days;	34.9 ± 1.5*	36.3 ± 2.2*	43.1 ± 4.5	48.5 ± 2.5*
after 4 months	41.1 ± 1.4	48.1 ± 2.4**	47.2 ± 3.9	54.8 ± 2.8**
LVP, W:				
Before CABG;	3.5 ± 0.2	3.4 ± 0.3	3.6 ± 0.4	2.9 ± 0.2
after 7 days;	2.6 ± 0.1*	3.0 ± 0.2	3.5 ± 0.4	3.5 ± 0.2*
after 4 months	3.3 ± 0.2	3.7 ± 0.2	4.0 ± 0.4	4.1 ± 0.3**
CI, l / min^2:				
Before CABG;	2.7 ± 0.1	2.8 ± 0.1	3.0 ± 0.2	2.7 ± 0.1
after 7 days;	2.6 ± 0.1	2.7 ± 0.1	2.9 ± 0.3	3.0 ± 0.1*
after 4 months	2.9 ± 0.1**	3.3 ± 0.2**	3.3 ± 0.2	3.6 ± 0.2**
LVET, sec:				
Before CABG;	300.3 ± 10.1	309.0 ± 17.3	365.9 ± 40.7	309.8 ± 16.1
after 7 days;	297.4 ± 11.6	268.0 ± 17.6	409.9 ± 55.1	326.9 ± 33.2
after 4 months	322.6 ± 13.0	326.8 ± 17.1	331.2 ± 33.7	378.8 ± 28.2
VFR, ml / sec:				
Before CABG;	285.1 ± 14.1	280.8 ± 19.7	294.9 ± 29.8	235.9 ± 27.3
after 7 days;	235.6 ± 12.2	261.3 ± 16.8	306.0 ± 29.1	252.1 ± 37.2
after 4 months	267.6 ± 11.8	296.9 ± 16.9	294.3 ± 27.0	292.8 ± 36.2
EDB, W·sec:				
Before CABG;	12.2 ± 0.2	11.7 ± 0.3	12.1 ± 0.5	11.5 ± 0.3
after 7 days;	11.1 ± 0.2*	11.2 ± 0.3	11.6 ± 0.4	11.7 ± 0.4
after 4 months	12.4 ± 0.3	12.9 ± 0.4**	12.9 ± 0.5	12.7 ± 0.5**

* statistical differences between baseline values and values on day 7 after the surgery:
CO, SV, SI $p < 0.001$ (group 4 $p < 0.005$); LVP (group 1 $p < 0.001$; group 4 $p = 0.015$); CI (group 4 $p < 0.001$); EDB (group 1 $p < 0.001$).
**statistical differences between baseline values and values 4 months after the surgery: CO $p < 0.05$; $p < 0.01$; SV $p < 0.005$; SI $p < 0.001$; CI < 0.005; EDB $p < 0.05$; ● statistical differences between the groups, $p < 0.05$.

According to the data obtained one week after the surgery, CO practically did not change, with the exception of patients in group 4 (off-pump CABG without PICS), in which this parameter increased from 4.8 ± 0.2 to 5.5 ± 0.2 l / min ($p < 0.001$). However, already 4 months after CABG in all patients, the mean value of LV CO was higher than before the surgery, and in the groups after off-pump CABG, this parameter was higher compared to patients who underwent on-pump surgery ($p < 0.05$). However, statistically significant differences were found only in the groups of patients without PICS.

One week after the surgery, LV SV and SI significantly decreased in patients operated with the aid of CPB and PCCC ($p < 0.001$), whereas in group 3, a decrease in these parameters was not significant ($p = 0.164$), and in group 4, on the contrary, their increase was statistically significant ($p = 0.005$). Four months after CABG, these parameters of LV hemodynamic remodeling in patients with a history of MI increased to values comparable to the baseline level. At the same time, the most pronounced increase in LV SV and SI was observed in group 4 without PICS.

In group 1 (with PICS), one week after CABG with the use of CPB and PCCC, there was a significant decrease in LV power ($p < 0.001$), whereas in groups 2 and 3 this parameter was comparable to the baseline values ($p = 0.093$ and $p = 0.397$, respectively). In

group 4 (without PICS after beating heart CABG), the level of LVP on day 7 after the surgery increased significantly ($p = 0.015$). Four months after the surgery, this parameter in all groups, except for group 4, turned out to be comparable to the baseline level, whereas in the latter, its further increase was observed. In group 4, there was a similar increase in CI.

Finally, changes in the energy spent for the displacement of one liter of blood through the LV one week after the surgery were characterized by a statistically significant decrease from 12.2 ± 0.2 to 11.1 ± 0.2 W • sec in patients of group 1 (with PICS and after on-pump CABG) ($p < 0.001$). In groups 1, 2, and 3, the values of EDB were comparable to the baseline level. Four months after the surgery, the average values increased in all groups, but a statistically significant increase was revealed in patients without MI. During the correlation analysis, moderate associations were obtained between the inotropic parameters of cardiac hemodynamics SV, SI, CO, LVP and blood pressure ($r\pi = 0.33–0.47$; $p < 0.001$), and noticeable associations were found between SV, SI, CO, LVP and EF ($r\pi = 0.63–0.68$; $p < 0.001$).

DISCUSSION

It is known that after direct myocardial revascularization, the heart adapts to new functioning conditions, which causes structural and functional remodeling [12]. The effect of the CABG type (on-pump or off-pump) on the parameters of intracardiac hemodynamics and cardiac remodeling is yet to be studied, since data on the changes in cardiac parameters in the postoperative period can be used both to assess the effectiveness of surgical treatment [13, 14] and to select a rehabilitation program for patients after bypass surgery, depending on the surgery type.

It is still not entirely clear how functional and anatomical remodeling of the LV occurs in the postoperative period and what role the surgery type (on-pump or off-pump) plays in it. However, already one week after CABG, and especially by the end of the 4th month, regardless of the type of surgery and MI in history, a decrease in LVMM, IST, LVPWT, and RWT was noted. Apparently, processes occurring after revascularization, which preserved the viability of the myocardium, contribute to rapid normalization of the structural and anatomical parameters of the myocardium and improvement of LV pumping function, which is confirmed by a significant increase in these parameters by the end of the follow-up.

Similar changes were noted in the volume parameters of the heart – LVED and LAV, which decreased. All this was accompanied by regular changes in the main parameter of myocardial contractility – EF, which first decreased and then reached the baseline level or even slightly increased [15]. However, all these changes were rather general and did not allow to identify differences in cardiac remodeling in both on-pump and off-pump CABG. In the end, surgical revascularization, regardless of the surgery type, led to positive structural and anatomical changes in the heart. In this situation, it seemed important to evaluate not only structural, but also hemodynamic cardiac remodeling in the groups after different types of CABG.

In this regard, a number of cardiac hemodynamic parameters were evaluated using VCO. This method is available, has no technical limitations, and can be easily reproduced in practice, which is especially important for consistent observation of changes. According to the results of this study, a significant difference was revealed in almost all the main hemodynamic parameters, such as CO, CI, SV, and SI of the LV, depending on the type of CABG. Thus, in group 1 (with PICS and after on-pump CABG), a decrease in these parameters was observed for 1 week, while in patients in groups 3 and 4 (off-pump CABG), the parameters decreased slightly. On the contrary, in group 4 (without PICS), a statistically significant increase in the parameters was noted. Four months after the surgery, hemodynamic parameters stabilized in all groups. However, in group 4, these parameters were significantly higher.

We did not reveal a close correlation between the parameters of TTE, VCO, and nonparametric data reflecting risk factors, concomitant diseases, PICS, and the number of shunts in the arteries. Therefore, we can assume that such dependence on the surgery type is associated not only with different severity of CHD in the groups, but also, probably, with the duration of surgery, traumas from surgical intervention, ischemic and reperfusion injuries, the fact that the procedure is not physiological and, of course, the cardiodepressive effect of the on-pump surgery.

According to various researchers, in on-pump CABG, suppression of cardiac hemodynamic parameters is noted almost two hours after surgery and leads to a decrease in EF on average from 50 to 30%. At the same time, cardiac contractility can be restored by the end of day 1 after CABG or even much later [16, 17]. Our data also confirm the cardiodepressive effect of on-pump CABG, which leads to a rapid decrease in LV power and a decrease in its EDB per 1 minute. At

the same time, after off-pump CABG, this decrease was practically not observed, which may be due to relatively rapid recovery of myocardial activity after hibernation, even in severe patients. At the same time, the history of MI significantly slowed down restoration of the inotropic function of the heart, regardless of the CABG type. Nevertheless, the systolic function stabilized much faster in the group of patients who underwent a beating heart CABG.

CONCLUSION

Thus, the surgery type affects not only the structural and anatomical remodeling of the heart, but also, largely, the parameters of cardiac hemodynamics in the postoperative period. In patients with CHD 7 days after off-pump CABG, there was a significant improvement in all parameters of inotropic heart function compared to patients who underwent on-pump surgery. Four months after off-pump CABG, the parameters of positive hemodynamic remodeling became even more noticeable than in patients after on-pump surgery. This indicates faster and better recovery of the myocardium and allows to optimize the rehabilitation program depending on the surgery type.

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Authors' contribution

Mayanskaya S.D., Abzalova G.F., Berezikova E.N. – conception and design.

Abzalova G.F. – collection and processing of material, statistical processing of the data. Mayanskaya S.D., Garaeva L.A. – drafting of the manuscript. Mayanskaya S.D., Abdulianov I.V., Teplyakov A.T., Grebenkina I.A. – editing of the manuscript.

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