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Lungs volume status and oxygen transport in patients with coronary artery disease with various types of comorbidity before and after coronary artery bypass grafting

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Aim. Assessment of lung volume status and oxygen transport system in patients with coronary artery disease (CAD) with different clinical types of comorbidity before and after coronary artery bypass grafting (CABG).

Material and methods. The observational controlled study included 66 patients with CAD with a median age of 67 years (95% confidence interval [59; 74]), admitted to the Far Eastern Federal University Hospital for elective CABG. Depending on the prevalence of clinical manifestations of comorbidities, CAD patients were ranked into 3 groups of comorbidity: cardiovascular, respiratory and metabolic. The first of them was represented by a combination of CAD and peripheral artery disease, the second — CAD and chronic obstructive pulmonary disease (COPD), the third — CAD and metabolic syndrome. All patients underwent isolated CABG under cardiopulmonary bypass (CPB). Volume and hemodynamic monitoring was carried out by transpulmonary thermodilution using the Pulsion PiCCO Plus (Germany) technology and the following indices: cardiac function index (CFI), extravascular lung water (EVLW), pulmonary vascular permeability index (PVPI). Pulmonary blood volume and oxygen transport indices were determined: oxygen delivery (DO_2I) and consumption (VO_2I) indices, oxygen-utilization coefficient, and pulmonary shunt fraction (Qs/Qt). The study was carried out in three stages: before the onset of CABG, after its completion and one day after CABG.

Results. The analysis of volume and hemodynamic monitoring data demonstrated the heterogeneity of their changes during CABG and one day after with different comorbidity profile. A more noticeable inhibition of the circulatory component of oxygen transport was revealed in patients with COPD, which was illustrated by the lowest CFI (3,2-3,4 ml/min) in relation to other groups of patients. The imbalance of cardio-respiratory interactions in this cohort after withdrawal from cardiopulmonary bypass was manifested by lower DO_2I and VO_2I and a maximum increase in Qs/Qt, exceeding 1,6 times the comparison groups. The respiratory and metabolic comorbidity of CAD was characterized by a significantly larger volume of extravascular lung water due to the higher permeability of the pulmonary vessels, which was documented by EVLW values, which exceeded the upper reference limit by 1,8-2 times and an increase in PVPI. In patients with cardiovascular comorbidity, lung volume violation was less noticeable.

Conclusion. A comprehensive analysis of lung volume status and oxygen transport makes it possible to more accurately assess the functional status of patients with CAD, to increase the effectiveness of risk stratification and toprevent possible complications during CABG and in the early postoperative period.

Keywords: coronary artery disease, comorbidity, oxygen transport, lung volume status, coronary artery bypass grafting.

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Coronary artery disease (CAD) is one of the main reasons of population disablement and mortality in most countries of the world. In the Russian Federation, the death rate from CAD is 322 cases per 100 thousand population, including the death rate from myocardial infarction, which reaches >40 cases per 100 thousand population per year [1]. Coronary artery bypass grafting (CABG) is one of the leading surgical technologies for blood flow recovery. Currently, our country performs ~24,5 surgical interventions per 100 thousand population per year, which is significantly lower than in a number of European countries (Germany, Poland), where the level of this indicator is ~50 surgical interventions per 100 thousand population [2]. It is emphasized that the increase in cardiac surgical activity should be provided with an increase in the requirements on quality of patient selection. This is especially important in CAD combination with some variants of comorbid pathology, which limits the CABG effectiveness due to increasing likelihood of postoperative complications and mortality. The most "aggressive" factors of surgical stress during CABG include artificial circulation (AC), during which functional and metabolic disorders develop due to tissue hypoperfusion, oxygen debt formation, accumulation of under-oxidized metabolic products in cells [3]. CABG with the use of AC affects simultaneously all components of the oxygen transport system: respiratory, circulatory, hemic, tissue [4]. The most important role in formation of oxygen deficiency in the tissues during CABG and in the early postoperative period belongs to respiratory component, which is due to a violation of oxygenating lung function associated with the background of alveolar tissue reperfusion and increased intrapulmonary blood bypass. The pathophysiological consequences of reperfusion processes are associated with extravascular fluid accumulation in the lungs due to an increase in the microvascular leakage and an increasing probability of acute lung damage. The presence of certain types of comorbid pathology in patients with CAD significantly worsens the initial status of hemocirculation and may be an additional risk factor for reperfusion disorders [5]. With that in mind, the performance of CABG with AC in patients of this category should be provided with more thorough volumetric and hemodynamic monitoring. One of its technologies includes transpulmonary thermodilution (TPTD), which allows a comprehensive assessment of pre- and after loading on the myocardium, its contractility, degree of pulmonary blood volume and pulmonary vessel permeability [6]. TPTD in combination with modern technical capabilities of blood gases test allows to most accurately determine the current status of the system-forming factors of oxygen transport: its delivery (DO_2), consumption (VO_2), utilization coefficient (O_2ER), fraction of pulmonary blood bypass (Qs/Qt). The use of this approach allows to timely diagnose and correct disorders of pulmonary hemodynamics and oxygen supply of tissues, which is especially important for patients with high-risk CAD associated with severe comorbidity [7].

The study's goal was to assess the pulmonary blood volume and the oxygen transport system in patients with CAD with different clinical comorbidity variants before and after CABG.

Material and methods

The observational controlled clinical study enrolled 66 patients with CAD (40 men and 26 women) aged 53 to 77 years with a median (Me) of 67 years and a 95% confidence interval (CI) [59; 74] who were admitted to the clinic of the Far Eastern Federal University for planned CABG in 2018-2019. Patients with a complicated course of postoperative period requiring long-term inotropic support and prolonged artificial lung ventilation were excluded from the study. The study protocols were approved by the local ethics committee of the School of Biomedicine of the Far Eastern Federal University and complied with the Helsinki Declaration of the World Association "Ethical Conduct of Scientific Medical Studies with Human Participation". Informed consent for the study was obtained from each patient. All patients underwent isolated CABG under AC conditions. Depending on clinical manifestation predominance of coexisting diseases, patients with CAD were ranked into 3 comorbidity groups: cardiovascular, respiratory, and metabolic. The first group included 24 patients with a combination of CAD and multifocal atherosclerosis (chronic lower limb ischemia and atherosclerotic narrowing of the carotid arteries ⩾50%). The second group consisted of 20 patients with chronic obstructive pulmonary disease (COPD) of the II-III degree without recrudescence. The third group was represented by 22 patients with CAD with cardiometabolic syndrome (CMS). Among the latter studied group, the body mass index was in the range of 31-34 kg/m^2, which shown first degree obesity. Patients of all groups were diagnosed with NYHA-class II-III chronic heart failure and controlled grade II-III arterial hypertension with a very high risk [8]. All patients before CABG received standard therapy for CAD, chronic heart failure and arterial hypertension, including nitrates, beta-blockers, angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers, calcium antagonists, fixed combinations with diuretics. In the preoperative period, loop diuretics

Table 1

Clinical and anamnestic characteristics of patients with CAD with various comorbidity variants

Indicators	CAD+PAT (n=24)	CAD+COPD (n=20)	CAD+CMS (n=22)	P-value
Age, years	62,3 [57; 64]	68,5 [61; 70]	66,7 [58; 69]	P_{1-2}=0,04; P_{1-3}=0,062; P_{2-3}=0,34
Men, n (%)	18 (75)	14 (70)	13 (59)	P_{1-2}=0,058; P_{1-3}=0,03; P_{2-3}=0,086
BMI, kg/m^2	25,7 [24,8; 27,3]	26,8 [25,4; 30,2]	32,6 [31,4; 33,8]	P_{1-2}=0,21; P_{1-3}=0,024; P_{2-3}=0,032
Anamnesis of MI, n (%)	8 (33,3)	6 (30)	5 (22,7)	P_{1-2}=0,42; P_{1-3}=0,035; P_{2-3}=0,14
AF, n (%)	2 (8,3)	3 (15)	3 (13,6)	P_{1-2}=0,15; P_{1-3}=0,48; P_{2-3}=0,76
Type 2 DM, n (%)	3 (12,5)	5 (25)	19 (86,4)	P_{1-2}=0,24; P_{1-3}<0,0001; P_{2-3}<0,0001
LV EF, (%)	64,5 [58; 65]	56,3 [54; 62]	61,3 [55; 66]	P_{1-2}=0,028; P_{1-3}=0,37; P_{2-3}=0,036
LV EF 30-50%, n (%)	2 (8,3)	5 (25)	3 (13,6)	P_{1-2}=0,026; P_{1-3}=0,15; P_{2-3}=0,04
GFR, ml/min/1,73 m^2	72,4 [67; 82]	64,5 [62; 74]	68,4 [63; 78]	P_{1-2}=0,017; P_{1-3}=0,065; P_{2-3}=0,38
AC duration, min.	89,8 [82,6; 97,7]	88,5 [84,3; 91,8]	90,3 [76,4; 101,3]	P_{1-2}=0,56; P_{1-3}=0,74; P_{2-3}=0,62

Note: $P_{1,2,3}$ — significance of differences between the experimental groups.

Abbreviations: CAD — coronary artery disease, AC — artificial circulation, MI — myocardial infarction, BMI — body mass index, CMS — cardiometabolic syndrome, PAT — lesions of peripheral arterial territory, DM — diabetes mellitus, GFR — glomerular filtration rate, LV EF — left ventricular ejection fraction, AF — atrial fibrillation, COPD — chronic obstructive pulmonary disease.

(torasemide) were used in 10 (15,2%) patients with clinical signs of congestion in the large circulatory system. The preoperative clinical and anamnestic status of patients with CAD of various groups and the duration of AC are presented in Table 1.

Blood volume and hemodynamic parameters were recorded by the TPTD method using the Dreger Delta XL monitor and the Pulse PiCCO Plus module (Germany) after catheterization of the brachial artery with the PV2015L20 equipment. The duration of its stay in the arterial bed was no more than 3 days. The arterial line flushing was carried out with boluses of 0,9% NaCl solution with 1 U/ml heparin. During calibration, three consecutive thermal dilutions were performed. The study of blood volume, cardiac pumping function and the calculation of oxygen transport parameters were performed at three stages of the study: immediately after tracheal intubation and beginning of artificial ventilation (phase I); after AC completion and heparin inactivation (phase II); 24 hours after surgery (phase III). Recorded the following parameters: extravascular lung water index (EVLW) and global end diastolic volume (GEDV), cardiac function index (CFI) = cardiac index (CI)/GEDV. The pulmonary blood volume (PBV) was calculated as the difference between GEDV and VSVL. The pulmonary vascular permeability index (PVPI) was determined by the EVLW/PBV ratio [9]. To calculate the oxygen transport parameters, the gas composition of arterial and mixed venous blood was determined using the Radiometer ABL — 800 gas analyzer (Denmark). The following parameters were recorded: PaO_2 — partial oxygen tension in arterial blood; SvO_2 — saturation of mixed venous blood taken from right atrium; $ctvO_2$ — oxygen concentration in mixed venous blood, $ctaO_2$ — oxygen concentration in arterial blood; DO_2I — oxygen delivery index =($CI \times ctaO_2$); VO_2I — oxygen consumption index =$CI \times (ctaO_2\text{-}ctvO_2)$. O_2ER was calculated by the ratio $(VO_2/DO_2) \times 100\%$, and pulmonary blood bypass (Qs/Qt) — by the formula:

$$Qs/Qt=(CcO_2-ctaO_2)/(CcO_2-ctvO_2),$$

where CcO_2 — oxygen concentration in alveolo-capillary blood [6]. The latter was found by the formula:

$$CcO_2=[(ctaO_2)\times(1,33)\times(SaO_2)]+[(RAO_2)\times(0,00314)],$$

where 1,33 — Hufner coefficient and 0,00314 — free dissolved oxygen in blood plasma.

Statistical data processing was performed using the software STATISTICA 10 (StatSoft, Inc., USA) and Excel (Microsoft Office 2018) in Windows 10 operating system. The hypothesis testing for normality of continuous character distribution in the analyzed groups was carried out using the Kolmogorov-Smirnov and Shapiro-Wilk criteria. The data analysis was performed using descriptive statistics: Me and their 95% CI. Paired intergroup differences were assessed using the nonparametric Mann-Whitney U-test. The differences were considered statistically significant at $p<0,05$.

Results

The study results showed that before the surgical intervention, all patients with CAD, regardless of the comorbidity clinical form, had systolic-diastolic myocardial dysfunction, as evidenced by a high level of GEDV (960-1120 ml) and low value of CFI (3,2-3,8 ml). After the departure from the AC and 24 hours after the surgical intervention in patients of all groups, GEDV decreased, but did not reach the upper

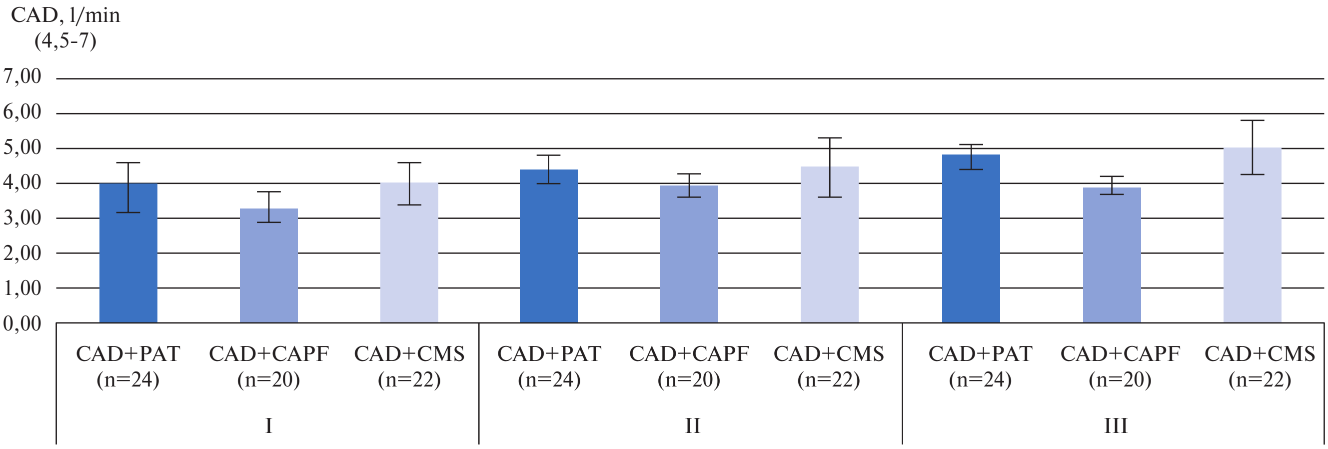

Figure 1. Dynamics of CFI changes at the research stages.
Note: the standard range of this indicator is shown in brackets.
Abbreviations: CAD — coronary artery disease, CFI — cardiac function index, CMS — cardiometabolic syndrome, PAT — lesion of peripheral arterial territory, COPD — chronic obstructive pulmonary disease.

limit of the reference range (800 ml). The dynamics of changes in CFI indicated an improvement in pumping ability of the heart within a day after CABG in patients with CAD with cardiovascular and metabolic comorbidity. In its respiratory variant, this indicator had a minimum value (3,4 l/min, with a norm of 4,5-7 l/min), which testified a more pronounced violation of cardiodynamics in this category of patients (Figure 1). In patients of all groups at the first stage of the study, the level of EVLW exceeded the standard values, but was highest among patients with respiratory and metabolic forms of comorbidity (Table 2). After AC completion, this indicator did not change significantly, and it significantly decreased after CABG, but did not reach the reference values. In patients with a combination of CAD and CMS, the EVLW level at the III stage of the study was higher than in those examined with other comorbidity variants, which may be due to the influence of excessive intraabdominal pressure on pulmonary hemodynamics [10]. PBV before surgery in the combination of CAD and COPD was significantly lower than in patients of other groups. After the departure from AC, all the patients showed a tendency to decrease its level, which persisted in the early postoperative period. Before surgical treatment, the PVPI level in all patients did not exceed the threshold value, but with a combination of CAD and COPD, it was higher than in patients of other groups. At the second stage of the study, the PVPI level in patients with CAD with respiratory and metabolic comorbidity significantly increased, which could indicate an increasing risk of acute lung injury. After 24 hours after CABG, a positive dynamics of changes in this parameter in all groups of subjects was noted.

In a comprehensive assessment of oxygen transport parameters, it was found that before surgical treatment, all patients had an increase in fraction of the pulmonary bypass, especially noticeable in the combination of CAD and COPD. At the second stage of the study, Qs/Qt in patients with respiratory comorbidity reached the maximum values and exceeded the upper limit of the reference level by 2,6 times. The venous admixture index in other comorbidity variants did not differ from each other and was 1,5-1,6 times higher than the standard values. After 24 hours after myocardial revascularization, the pulmonary bypass fraction was normalized in all the study groups. The dynamic pattern in the PaO_2 index indicated that in patients with CAD with respiratory comorbidity at all stages of follow-up, its level was lower than in the experimental groups. These differences may be due to the initial limit of ventilation and blood oxygenation in COPD as a result of remodeling of conductive and respiratory parts of the respiratory system, which reduces the lung volume and the pulmonary ventilation effectiveness. The SvO_2 index during the study was within the limits of physiological norm (70-80%) and did not depend on clinical variant of comorbidity. This can be explained by the fact that the SvO_2 level in hypothermia significantly increases, decreases by the end of warming and almost normalizes after AC switch off, which was confirmed by the results of our study. When assessing the oxygen delivery to the tissues over time, it was noted that the DO_2 level before CABG in patients with respiratory comorbidity was lower than in other variants. In this group, the minimum values of the DO_2 index were fixed after the departure from AC, and a day after CABG, this tendency continued.

Table 2

Indicators of pulmonary blood volume and oxygen transport in patients with CAD with various comorbidity variants (Me, 95% CI)

Indicators and their standard values	Stages of research									P-value
	I			II			III			
	CAD PAT (n=24)	CAD COPD (n=20)	CAD CMS (n=22)	CAD PAT (n=24)	CAD COPD (n=20)	CAD CMS (n=22)	CAD PAT (n=24)	CAD COPD (n=20)	CAD CMS (n=22)	
PBV, ml (170-200)	437,94^{1} [395,75; 480,14]	395,33^{2} [369,74; 420,92]	487,1^{3} [398,93; 574,62]	392,47^{4} [359,34; 425,6]	356^{5} [307,1; 444,9]	370,8^{6} [315,11; 426,67]	396,82^{7} [350,1; 443,7]	350,83^{8} [313,1; 389,1]	361,78^{9} [293,65; 429,91]	P_{1-4}=0,002; P_{1-7}=0,035; P_{2-5}=0,84; P_{2-8}=0,13; P_{3-6}=0,015; P_{3-9}=0,32
EVLW, ml/kg (3-7)	10^{1} [8,4; 11,6]	13,6^{2} [12,2; 15,1]	14,2^{3} [13,1; 15,4]	11,2^{4} [9,1; 13,25]	14,3^{5} [12,1; 17,1]	13,07^{6} [11,8; 14,3]	7,88^{7} [7,16; 8,6]	10^{8} [9,1; 11]	12^{9} [10,2; 13,8]	P_{1-4}=0,15; P_{1-7}=0,068; P_{2-5}=0,08; P_{2-8}=0,044; P_{3-6}=0,37; P_{3-9}=0,027
PVPI, c.u. (1-3)	1,57^{1} [1,32; 1,82]	2,22^{2} [1,94; 2,5]	1,71^{3} [1,35; 2,1]	1,66^{4} [1,45; 1,87]	2,49^{5} [2,22; 2,7]	2,52^{6} [2,32; 2,72]	1,64^{7} [1,4; 1,8]	1,8^{8} [1,7; 2]	1,84^{9} [1,7; 2,0]	P_{1-4}=0,08; P_{1-7}=0,036; P_{2-5}=0,03; P_{2-8}=0,018; P_{3-6}=0,032; P_{3-9}=0,13
Qs/Qt, (4-10%)	14^{1} [10; 18]	16^{2} [9; 25]	13^{3} [8; 18]	15^{4} [19; 22]	26^{5} [15; 37]	16^{6} [10; 23]	7^{7} [3; 10]	8^{8} [5; 12]	6^{9} [3; 9]	P_{1-4}=0,08; P_{1-7}=0,032; P_{2-5}=0,018; P_{2-8}=0,015; P_{3-6}=0,034; P_{3-9}=0,0016
DO_2I, (420-720 ml/min/m^2)	551,3^{1} [480,68; 622,08]	511,47^{2} [463,46; 558,23]	629,21^{3} [508,15; 750,27]	450,1^{4} [408,43; 490,97]	416,2^{5} [381,12; 450,21]	456,62^{6} [380,4; 532,82]	519,22^{7} [471,9; 566,5]	449,58^{8} [329,93; 569,24]	548,2^{9} [451,11; 638,37]	P_{1-4}=0,004; P_{1-7}=0,51; P_{2-5}=0,015; P_{2-8}=0,083; P_{3-6}=0,034; P_{3-9}=0,042
VO_2I, (200-250 ml/min/m^2)	177,37^{1} [135,3; 219,4]	149,12^{2} [38,1; 260,13]	192,45^{3} [118,1; 266,8]	107,07^{4} [86,5; 127,6]	92,37^{5} [19,56; 65,19]	141,45^{6} [117,2; 165,7]	131,8^{7} [103,85; 159,83]	120,33^{8} [66,25; 174,4]	171,52^{9} [107,28; 235,76]	P_{1-4}=0,015; P_{1-7}=0,14; P_{2-5}=0,026; P_{2-8}=0,91; P_{3-6}=0,11; P_{3-9}=0,43
O_2ER, (20-30%)	0,32^{1} [0,26; 0,38]	0,31^{2} [0,19; 0,43]	0,3^{3} [0,23; 0,37]	0,24^{4} [0,2; 0,28]	0,22^{5} [0,19; 0,23]	0,32^{6} [0,26; 0,38]	0,25^{7} [0,21; 0,29]	0,22^{8} [0,19; 0,25]	0,31^{9} [0,22; 0,39]	P_{1-4}=0,053; P_{1-7}=0,06; P_{2-5}=0,002; P_{2-8}=0,034; P_{3-6}=0,3; P_{3-9}=0,47

Note: P_{1-9} — reliability of differences in indicators between stages of the study. The standard values are shown in brackets.

Abbreviations: PAT — lesions of peripheral arterial territories, EVLW — index of extravascular water of the lungs, PBV — pulmonary blood volume, PVPI — pulmonary vascular permeability index, Qs/Qt — fraction of veno-arterial blood bypass, DO_2 — index of oxygen delivery, VO_2 — oxygen consumption index; O_2ER — oxygen utilization coefficient.

The dynamic pattern analysis on the VO_2I oxygen delivery showed that its level did not reach the lower limit of physiological norm in the entire cohort of subjects at any point of measurement. The most significant decrease in this indicator (by 2.2 times) was recorded in patients with cardio-respiratory comorbidity after departure from AC and a day after CABG. The O_2ER oxygen utilization index due to the optimal ratio of calculated components (VO_2 and DO_2) at all stages of observation did not go beyond the standard values (20-30%). When departure from AC and 24 hours after it, the level of this indicator in patients with CAD with CMS was significantly higher than in other comorbidity variants, which can be explained by a higher need for energy supply and the intensity of intracellular metabolism in overweight individuals.

Discussion

The main purpose of monitoring physiological functions in cardiac surgery is to obtain timely data on the current status of regional and systemic blood circulation, tissue oxygen demand and its actual delivery. It is shown, for example, that in CABG, the SvO_2 value at the level of 60% or less increases the risk of intrahospital mortality by 5,4% and is more often accompanied by intra- and postoperative complications [11]. The need for careful monitoring of the hemocirculation parameters and other factors of oxygen transport increases significantly with the CAD comorbidity, which initially reduces the functional reserves of these systems. In our study, the use of TPTD technology with the calculation of individual indicators of hemodynamics, lungs volume status and oxygen transport allowed to verify the phenotypic features of blood circulation and oxygen supply of tissues in different variants of CAD comorbidity during CABG and in the immediate postoperative period.

The study's results showed that the preoperative clinical and anamnestic status of patients with CAD with certain forms of comorbidity had certain differences (Table 1). Thus, in its respiratory variant, the ejection fraction level was significantly lower than in the comparison groups, which indicated a more noticeable limit of systolic function in this category of patients. A more pronounced violation of the heart contractile function in the combination of CAD and COPD was also indicated by the indicators of CFI and GEDV, which are referred to the "gold standards" for assessing its contractile potential, which allow to detail the circulatory-volume status of patients [12]. The prevalence of right ventricular failure in patients with COPD was indicated by the PBV level, which was significantly lower than in other comorbidity variants. The obtained results demonstrate a more expressed limit of the circulatory link functions in the oxygen transport system in this category of patients.

The EVLW and PVPI indicator analysis allowed to differentially assess the lungs volume status, depending on the clinical forms of comorbid pathology. Thus, the maximum values of EVLW and PVPI were recorded among patients with CAD with respiratory and metabolic comorbidity. An increase in blood volume level indicators in patients with COPD is associated with increased permeability of the capillary bed as a result of pathological modifications of the lung tissue due to emphysematous-pneumosclerosis processes, chronic systemic inflammation, pulmonary hypertension and disorders of the mechanisms of intercellular space drainage [12]. The main pathogenetic factors of extravascular fluid accumulation in the lungs by combination of CAD and CMS may include excessive intra-abdominal pressure, a decrease in functional activity of the diaphragm with a limit of lung volumes and microatelectasis of basal lung segments, an imbalance in synthesis of adipokines with a predominance of their vasoconstrictor pool [13]. According to the literature data, the main reason for the ventilation violation in CABG under AC conditions is an increase in the pulmonary bypass fraction [9]. In the present study, in all patients with CAD before surgical treatment and after departure from AC, the venoarterial bypass fraction was higher than the standard values and reached the maximum level in respiratory comorbidity, which was associated with violation of ventilation-perfusion relations as a result of subclinical pulmonary edema and was confirmed by the EVLW indicator. The increase in venous impurity in patients with COPD is associated with an expressed endothelial dysfunction of the pulmonary vessels, which leads to violation of regulation of their tone and prevents the effective implementation of the Euler-Liljestrand reflex, which leads to the preservation of blood flow in unventilated alveoli [5]. After departure from AC, the increase in venous admixture may also be due to peripheral bypass in the microcirculatory bed of the large circulatory circle with limited oxygen extraction, which in our study was confirmed by a low level of O_2ER. 24 h after surgery veno-arterial bypass fraction in patients of all groups were significantly reduced due to involvement in the process of respiration unventilated alveoli and limit the amount of extravascular fluid in the lungs, which illustrated by the EVLW dynamics. Despite the presence of chronic heart failure in all patients, the O_2 oxygen delivery index before the start of CABG did not exceed the reference values, and the level of its consumption was moderately reduced. This may be due to the pharmacological effects of combinations of opiate drugs, halogenated inhaled anesthetics and neuromuscular blocking agents that reduce the need for energy supply. At the second stage of the study, patients with respiratory comorbidity showed the most noticeable decrease in oxygen consumption, which persisted 24 hours after CABG, which is associated with a higher risk of hypoxic tissue damage and multiple organ failure.

The limitations of this study include a relatively small number of observations, which requires the analyzed sample expansion, taking into account the features of initial clinical and functional status of patients, intraoperative factors and the use of multivariate analysis methods for data processing.

Conclusion

The study's results indicate the heterogeneity of changes in the circulatory-volume status and oxygen transport in patients with CAD with various comorbidity variants. A more noticeable inhibition of the circulatory component of oxygen transport occurs in patients with COPD due to a pronounced decrease in contractile function of the myocardium. The imbalance of cardiorespiratory interactions in this cohort of patients was illustrated by lower parameters of oxygen delivery and consumption compared to patients without pulmonary pathology. Respiratory comorbidity of CAD was also manifested by the maximum increase in intrapulmonary blood bypass, which worsens the oxygen supply of tissues. Violations of the lungs volume status as a result of increased permeability of the pulmonary capillaries and accumulation of extravascular fluid were more often recorded in respiratory and metabolic comorbidity. A comprehensive analysis of the lungs volume status and oxygen transport in comparison with the "nosological" portrait of comorbid pathology of patients with CAD makes it possible to increase the effectiveness of risk stratification and prevention of possible complications during CABG and in the early postoperative period.

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