

The Tactics of Weaning from Cardiopulmonary Bypass with Blood-saving Technique in Cardiac Surgery

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ABSTRACT

BACKGROUND: Cardiac surgery under cardiopulmonary bypass is typically characterized by significant blood loss and the need for donor red blood cell transfusions. In addition to the inflammatory response, hemodilution, hypocoagulation, and blood loss significantly contributes to the development of perioperative anemia associated with the weaning from the cardiopulmonary bypass. **AIM:** Optimization of weaning from cardiopulmonary bypass to reduce blood loss during cardiac surgery. **METHODS:** Patients undergoing cardiac surgery under cardiopulmonary bypass ($n=62$) were divided into two groups. In the study group ($n=31$), all blood from cardiopulmonary bypass circuit was returned to the patient's central vein at the end of the cardiopulmonary bypass. In the comparison group ($n=31$), a standard method of pushing a residual blood volume from the cardiopulmonary bypass circuit with normal saline was used. Laboratory and instrumental data were analyzed. **RESULTS:** Intraoperative blood loss in the study group was significantly lower than in the comparison group (500 [470–520] ml versus 800 [760–830] ml, $p=0.0001$). Twenty-four hours after surgery, creatinine, alanine aminotransferase, and amylase concentrations were higher in the study group than in the comparison group. At the end of surgery, the study group also had higher cardiac index (3.1 [2.8–3.6] versus 2.8 [2.6–3.1] l/m² per minute, $p=0.018$) and global ejection fraction (28 [22–31] versus 22 [19–24]%, $p=0.011$). No adverse events or reactions were registered during the study. **CONCLUSION:** Complete blood return after cardiopulmonary bypass results in higher hemoglobin and hematocrit levels in the early postoperative period, accompanied by less blood loss and higher cardiac index and global ejection fraction after the main stage of the surgery without significant adverse events.

Keywords: artificial circulation; blood loss; hemohydrobalance; cardiosurgery.

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BACKGROUND

The procedure of cardiopulmonary bypass (CPB) is a potent stress for the organism, which may be accompanied by pronounced pathophysiological reactions [1]. CPB may result in the development of systemic inflammatory response, anemia, increased risks of perioperative hemorrhages due to the hemodilution (a decrease in the number of red blood cells in blood plasma resulting from the increase in the total plasma volume), due to the decreased levels

of coagulation factors and due to the dysfunction of platelets [2].

Cardiac surgery is considered the leading field by the number of post-operative blood loss and by the development of post-operative hemorrhages. An important step of the CPB is its termination, for the volume of blood remaining after the CPB procedure in the oxygenator and the pipelines, significantly affects the development of the post-operative anemia. However, currently the medical published literature contains no

Тактика завершения процедуры искусственного кровообращения в рамках кровосберегающей концепции при кардиохирургических операциях

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АННОТАЦИЯ

Обоснование. Кардиохирургические вмешательства в условиях искусственного кровообращения обычно характеризуются значительной кровопотерей и потребностью в переливании донорских компонентов крови. Помимо системной воспалительной реакции, гемодилюции и гипокоагуляции, важный вклад в развитие периоперационной анемии вносит кровопотеря, связанная с этапом завершения искусственного кровообращения. **Цель** — оптимизация этапа завершения искусственного кровообращения для уменьшения кровопотери при кардиохирургических операциях. **Методы.** Прооперированные в условиях искусственного кровообращения пациенты (n=62) разделены на две группы. В основной группе (n=31) по окончании процедуры искусственного кровообращения весь объем крови из всех магистралей аппарата искусственного кровообращения возвращали в центральную вену пациента. В группе сравнения (n=31) использовали стандартный метод отдачи остаточной крови из контура искусственного кровообращения с помощью вытеснения физиологическим раствором. Анализировали данные лабораторных и инструментальных методов исследования. **Результаты.** Интраоперационная кровопотеря в основной группе была значимо ниже, чем в группе сравнения (500 мл [470–520] против 800 мл [760–830], $p=0,0001$). Через 24 часа после операции концентрация креатинина, аланинаминотрансферазы и амилазы были выше в основной группе, чем в группе сравнения. В конце операции в основной группе также были выше сердечный индекс (3,1 [2,8–3,6] против 2,8 [2,6–3,1] мл/мин/м², $p=0,018$) и глобальная фракция изгнания (28 [22–31] против 22 [19–24]%, $p=0,011$). Нежелательные явления и реакции во время проведения исследования отсутствовали. **Заключение.** Полный возврат крови после искусственного кровообращения в организм пациента приводит к увеличению показателей гемоглобина и гематокрита в раннем послеоперационном периоде, сопровождается меньшим объемом кровопотери и более высокими уровнями сердечного индекса и глобальной фракции изгнания после основного этапа операции на фоне отсутствия значимых нежелательных явлений.

Ключевые слова: искусственное кровообращение; кровопотеря; гемогидробаланс; кардиохирургия.

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algorithms for finishing this procedure. The blood-saving techniques in cardiac surgery include the transfusing blood from CPB circuit to the Cell Saver [3]. This method

is considered expensive and unavailable in some centers, necessitating optimization of the weaning from the CPB for decreasing the blood loss after heart surgery.

In cases of significant blood loss, for correcting the anemia, generally, the donor blood components are being used, though recently more attention in the medical literature is gained by various aspects of the necessity to minimize the transfusions of donor blood components [4]. This is related to the results of a large number of research works confirming that the transfusion of donor blood components is accompanied by an increase in the number of post-operative complications and in the number of hospitalization days, by the increase in the morbidity and mortality rates, as well as the increase in the costs of treating the patient [5].

Research aim — Optimization of weaning from cardiopulmonary bypass to reduce blood loss during cardiac surgery.

METHODS

Research design

This research is open-label, prospective and randomized.

Conformity criteria

Inclusion criteria: patients admitted to the Cardiosurgery Department of the Federal State Budgetary Institution “Federal Clinical Center of High Medical Technologies” under the Federal Medical-Biological Agency (FSBI FCC HMT under the Russian FMBA), of any gender, aged older than 18 years, in which the scheduled cardiosurgery intervention is planned in the settings of artificial circulation.

Exclusion criteria: emergency surgical intervention.

Non-inclusion criteria: aged under 18 years; individuals refusing to participate in the research.

Research facilities

The research was carried out within the premises of the Center for Cardio-Vascular and Endovascular Surgery of the FSBI FCC HMT of the Russian FMBA.

Research Duration

The research was carried out during the period from October 2023 until March 2024.

Medical procedure description

The research has enrolled 62 adult cardiosurgery patients operated in the settings of CPB, which were divided into two groups. In the main group ($n=31$) upon the end of CPB, the whole volume of blood from all the pipelines of the artificial circulation equipment was returned into the central vein of the patient via the laboratory shunt pipe attached to the aortic cannula. In

the comparison group ($n=31$), a traditional method was used that included the substitution of residual blood in the pipelines of the bypass after the completion of CPB. With the traditional method, after the end of the CPB procedure, the volume of blood remaining in the cardiotomy reservoir was returned to the vascular system of the patient via the aortic cannula. The blood remaining in the pipelines was relocated by displacing with an additional volume of normal saline (approximately 400 ml). After the decannulation of the aorta, the volume of blood remaining in the pipelines, was discarded.

The methods of perfusion and anesthetic management did not differ between the groups: for the induction of anesthesia, Midazolam was used (0.1 ± 0.02 mg/kg) along with Propofol (1.1 ± 0.08 mg/kg), Fentanyl (7.0 ± 0.3 µg/kg), Rocuronium bromide (0.9 ± 0.03 mg/kg); for maintaining the anesthesia — Sevoflurane (0.5–1 MAC, where the MAC is the minimal alveolar concentration); Fentanyl (1.9 ± 0.3 µg/kg per hour), Propofol (with the target concentration being 1.5 ± 0.1 mg/ml during the CPB) and Rocuronium bromide (0.3 ± 0.03 mg/kg per hour).

Perfusion methods: volumetric flow rate of the perfusion — 2.5 l/m² per minute, non-pulsatile mode, temperature mode: 35.8 – 36.7°C .

The patients were receiving blood cardioplegia using the Calafiore’s method (cardioplegia type 1) or crystalloid cold antegrade cardioplegia by Custodiol solution with the separate cannulation of the upper and the lower vena cava and with further removal of the cardioplegia solution into the external drainage via the coronary sinus (cardioplegia type 2).

The prime volume of CPB was: Gelofusin (500 ml), Sterofundin (750 ml), 15% Mannitol solution (150 ml) and 5% Sodium hydrocarbonate solution, NaHCO_3 (100 ml).

Methods for registration of outcomes

The parameters of the central blood circulation were measured using the PiCCO technology (Pulse index Continuous Cardiac Output) and the following parameters were analyzed: the cardiac index, the global ejection fraction, the index of the global function of the left ventricle, the extravascular lung water and the systemic vascular resistance index.

None of the patients in the research had received the transfusion of the donor blood components.

An analysis of the intraoperative data included the acid-base balance, the central (transpulmonary thermodilution method, PiCCO technology) and

the systemic hemodynamics before the operation, at the 5, 30 and 60 minutes stages of CPB and after finishing the CPB along with the sternal closure.

During the post-operative period, the analyzed values included the parameters of the general (clinical) and the blood biochemistry panels, the acid-base balance, the duration of mechanical ventilation, the length of stay in the Intensive Care Unit and the mortality rates.

Statistical analysis

The statistical analysis of the data was done using the SPSS 26.0 software pack (IBM Corp., New York, USA). The continuous and the categorical variables were presented as the median (Me) and the quartiles (25%; 75%) or *n* (%) depending on the type of data. The comparison of the quantitative characteristics among the groups was carried out using the Mann-Whitney test. For evaluating the significance of the differences between the categorical variables, the χ^2 (2×2) tests were used with the Yates's correction. When evaluating the dynamic intragroup data, the Wilcoxon criterion was applied. When checking the statistical hypotheses, the statistical significance was established with the *p* value of <0.05.

RESULTS

Research sample (participants)

The patients from the Center for Cardio-Vascular and Endovascular Surgery of the FSBI FCC HMT of the Russian FMBA, operated in the settings of artificial

circulation (*n*=62), were divided into two groups — the main one (*n*=31; after finishing the CPB, the whole blood volume from all the pipelines of the artificial circulation equipment returning to the central vein of the patient via the laboratory shunt pipeline attached to the aortic cannula) and the comparison group (*n*=31; traditional method of displacing the residual blood from the artificial circulation equipment pipelines after the completion of CPB).

The groups were comparable by the age, the gender, the duration of CPB, the duration of surgery, as well as by the baseline values of the biochemistry and clinical hematology panels, as well as by the coagulation panel findings, by the data from the instrumental examinations, by the spectrum of conducted surgical interventions, by the time of myocardial ischemia and by the concomitant diseases (table 1, 2).

Primary findings

No significant differences were found in the intraoperative hemoglobin and hematocrit levels between the groups (table 3).

In the main group, during the surgery, an increase was found in the volume of fluid administered during the CPB (table 4). It was probably related to the necessity of supporting the sufficient filling volume for the cardiectomy reservoir at the main phase of surgery.

The total intraoperative blood loss in the main group was significantly lower comparing to the one in

Table 1

Demographical and laboratory data

Parameter	Group		<i>p</i>
	Main <i>n</i> =31	Comparison <i>n</i> =31	
Age, years	67 [57–69]	65 [56–69]	0.405
Body weight, kg	84 [75.8–95.0]	80 [71–90]	0.337
Body mass index, kg/m ²	28.9 [26.5–36.6]	26.7 [24.9–30.8]	0.062
Males, <i>n</i> (%)	19 (61)	23 (74)	0.277
Creatinine, μ mol/l	89 [80–106]	91 [75–99]	0.756
Alanine aminotransferase, u/l	17 [16–27]	19 [13–24]	0.820
Amylase, u/l	53 [42–90]	84 [35–104]	0.846
Red blood cells, thous./ μ l	4.81 [4.35–4.95]	4.76 [4.37–5.01]	0.947
Hemoglobin, g/l	139 [131–147]	143 [129–151]	0.564
Hematocrit, %	41.8 [38.4–44.0]	41.5 [37.5–45.6]	0.830
Platelets, thous./ μ l	227 [195–271]	242 [187–286]	0.679
Prothrombin, %	104 [93–108]	99 [91–104]	0.188
Fibrinogen, g/l	5.7 [4.3–7.5]	5 [4.2–6.7]	0.228

Table 2

Characterization of surgeries

Parameter	Group		p
	Main n=31	Comparison n=31	
Plegia type 1, n (%)	23 (74)	22 (71)	0.766
Coronary artery bypass grafting, n (%)	2 (6.5)	2 (6.4)	0.380
Valve, n (%)	22 (71)	26 (83.9)	
Combined, n (%)	7 (22.5)	3 (9.7)	
CPB duration, min	58 [46–81]	63 [53–81]	0.436
Duration of myocardial ischemia, min	43 [33–58]	50 [40–60]	0.406

Note. CPB — cardiopulmonary bypass.

Table 3

Comparison of intraoperative parameters

Parameter	Group		<i>p</i> Mann–Whitney test
	Main <i>n</i> =31	Comparison <i>n</i> =31	
<i>Beginning of surgery</i>			
Hemoglobin, g/l	128 [116–130]	124 [113–131]	0.917
Hematocrit, %	38 [35–39]	36 [33–37.5]	0.086
<i>5 minutes of CPB</i>			
Hemoglobin, g/l	92 [82–100]	90 [80–103]	0.860
Hematocrit, %	26.5 [22.5–30.5]	24 [20–26.5]	0.138
<i>30 minutes of CPB</i>			
Hemoglobin, g/l	96 [87–102]	91 [80–104]	0.397
Hematocrit, %	28 [23–29]	23 [21–26]	0.062
<i>60 minutes of CPB</i>			
Hemoglobin, g/l	96 [83–103]	93.5 [86–105]	1.000
Hematocrit, %	29 [21–32.5]	26 [23.3–26.8]	0.256
<i>After CPB</i>			
Hemoglobin, g/l	105 [98–113]	105 [94–116]	0.920
Hematocrit, %	31 [27–34]	27 [25–32]	0.108

Note. CPB — cardiopulmonary bypass.

the comparison group. This is related to the fact that when using the “standard” method for finishing the AC procedure, approximately 300 ml of blood mixed with physiological solutions remains in the oxygenator and in the pipelines.

In the main group, significant difference was found between the levels of hemoglobin and hematocrit during the first post-operative 24h.

The levels of creatinine, alanine-aminotransferase and amylase in 24 hours after surgery were significantly higher in the main group than in the comparison group, with this, all the parameters were within the reference ranges. We have also found a tendency to later extubation in the main group. The hydrobalance values

during the first post-operative 24h did not significantly differ between the groups. Additional evaluation was conducted for the volume of primary filling (ml/kg of the body weight of the patient) and for the intraoperative balance: no significant difference was found between these parameters (see table 4).

The cardiac output parameters before the sternal closure between the groups did not significantly differ. After the sternal closure, the cardiac index and the global ejection fraction were significantly higher in the main group with the comparable dosages of catecholamines (table 5). In the comparison group, the index of the global function of the left ventricle has significantly decreased comparing to the baseline value.

Table 4

The comparison of the parameters during the first post-operative 24h

Parameter	Group		p Mann–Whitney test
	Main n=31	Comparison n=31	
Creatinine, $\mu\text{mol/l}$	106 [78–125]	85 [73–105]	0.015*
Alanine aminotransferase, u/l	24 [16–52]	18 [12–27.3]	0.045*
Amylase, u/l	98 [68–276]	60 [44–140]	0.009*
Red blood cells, thous./ μl	3.9 [3.5–4.2]	3.65 [3.22–4.06]	0.309
Hemoglobin, g/l	116 [104–124]	103.5 [93–119]	0.028*
Hematocrit, %	33 [30–36]	29.5 [25.5–33]	0.014*
Platelets, thous./ μl	158 [119–207]	170 [148–219]	0.319
MV less than 6 h, n (%)	11 (35.5)	5 (16)	0.069
Blood loss, ml	500 [470–520]	800 [760–830]	0.001*
Hemohydrobalance, ml			
• intraoperative	1240 [600–1893]	1150 [800–1513]	0.081
• per 24 h	1475 [1013–1725]	1075 [450–1725]	0.135
Drainage tubes, ml	250 [190–335]	250 [187–320]	0.704
Volume of administered fluid during the CPB, ml	2000 [1800–2300]	1833 [1700–1800]	0.003*
Prime, ml/kg	22.5 [20.68–26.13]	22.78 [20.9–27.05]	0.539
Intraoperative fluid balance, ml/kg	13.34 [9.72–18.12]	16.66 [12.62–20.62]	0.203

Note. MV — mechanical ventilation; CPB — cardiopulmonary bypass. * parameters achieving the statistical significance.

Table 5

Parameters of the central blood circulation

Parameter	Group		<i>p</i> Mann–Whitney test
	Main <i>n</i> =31	Comparison <i>n</i> =31	
<i>Before sternal closure</i>			
Dopamine, µg/kg per minute	4.64 [4–5]	4.58 [4–5]	0.752
CI, l/m ² per minute	3.1 [2.8–3.3]	3.35 [3.0–3.6]	0.440
GEF, %	26 [21–30]	23 [18–28]	0.185
IGF, ml/m ²	761 [660–824]	753 [665–900]	0.683
EVLW, ml/kg	8 [7.5–9.5]	8 [7–10]	0.618
SVRI, dynes*sec*cm ⁻⁵ /m ²	1709 [1400–2000]	1365 [1300–1592]	0.157
<i>After sternal closure</i>			
CI, l/m ² per minute	3.1 [2.8–3.6]	2.8 [2.6–3.1]	0.018*
GEF, %	28 [22–31]	22 [19–24]	0.011*
GEF, >25%, <i>n</i> %	17 (55)	5 (16)	0.001*
IGF, ml/m ²	775 [643–872]	647 [615–820]	0.142
EVLW, ml/kg	9 [8.5–11.0]	9 [7–10]	0.097
SVRI, dynes*sec*cm ⁻⁵ /m ²	1800 [1400–2153]	1974 [1624–2385]	0.386

Note. CI — cardiac index; GEF — global ejection fraction; IGF — index of the global function of the left ventricle; EVLW — extravascular lung water; SVRI — systemic vascular resistance index. * parameters achieving the statistical significance.

Undesirable phenomena

There were no significant adverse events during the complete blood return after CPB into the organism of the patient during the ten days period.

DISCUSSION

Complete blood return after cardiopulmonary bypass results in higher hemoglobin and hematocrit levels in the early postoperative period, accompanied by less blood loss and higher cardiac index and global ejection fraction after the main stage of the surgery. The increase in the hemohydrobalance at the intraoperative period in the patients operated in the settings of CPB, can contribute to the development of multiorgan dysfunction.

The results obtained during this research confirm the high priority of the blood saving tactics, for significantly higher values were demonstrated for hemoglobin and hematocrit during the first post-operative 24h in the group of patients, in which a complete blood return was done from the pipelines of the artificial circulation equipment into the organism. This matches to the numerous literature data on the practicability and the necessity of implementing the blood-saving technologies into the routine surgery practice [6]. Based on the research results, a significant decrease of the intraoperative blood loss was achieved, which contributed to the decrease in the probability of using the donor blood components. Besides, in the main group, higher values were shown for the cardiac index in the post-perfusion period. The integrity of the contractile function is one of top-priority tasks among the cardiosurgery patients, while its decrease is directly related to the increase in the number of complications during the post-operative period along with the increased in-hospital mortality [7].

According to the data from our research work, in the main group, the fluid balance was significantly higher than in the comparison group one, which, on the one hand, combined with the higher values of red blood, was resulting in the improvement of the cardiac index, while on the other — it has entailed all the drawbacks of increased cumulative hydrobalance. Indeed, achieving the balance between the limitation in the volume of infusion and maintaining the adequate preload periodically can pose a certain problem.

It is known that the liberal infusion tactics, especially with a background of systemic inflammatory response syndrome in cardiac surgery, may result

in the development of interstitial edema and multi-organ dysfunction [8]. The higher fluid balance group had higher levels of creatinine, amylase, and alanine aminotransferase during the first 24 hours after surgery, as well as a tendency toward longer (more than 6 hours) postoperative mechanical ventilation. These data completely match to the results from a number of research works, where it was proven that higher fluid balance increases the ventilation time, while the prolong mechanical ventilation increases the risk of unfavorable outcome [9].

One of the variants for optimizing the CPB finishing stage with following the tactics of maximal blood saving without increasing the cumulative hydrobalance is the usage of the autotransfusion equipment and washing off the red blood cells remaining in the CPB circuit with removing the excess fluid [10], however, this method leads to the additional trauma for the blood corpuscles and, according to the data from some authors, can worsen the treatment results [11]. Indeed, the optimal approach to managing the cardiosurgery patients, operated in the settings of CPB, is the maximal blood-saving tactics [12] combined with a decreased volume of perioperative infusion therapy. The present trial has demonstrated the method for the possible increase in the values of the cardiac index and for decreasing the blood loss during the post-operative period, which, in turn, can reduce the risk of developing complications among the cardiosurgery patients.

Thus, the complete return of blood after the CPB via the laboratory shunt loop into the organism of the patient results in an increase in the values of hemoglobin and hematocrit within the early post-operative period, being accompanied by lesser volume of blood loss and higher levels of the cardiac index and of the global ejection fraction after the main surgery phase. Positive hydrobalance could lead to the development of multi-organ dysfunction.

Research limitations

The research work has a number of the following limitations: single center involved with a small sample of patients; the patients were admitted for scheduled surgical intervention and had no severe concomitant diseases.

CONCLUSION

Thus, the complete blood return after cardiopulmonary bypass results in higher hemoglobin and hematocrit levels in the early postoperative period, accompanied

by less blood loss and higher cardiac index and global ejection fraction after the main stage of the surgery. Also not being associated with significant adverse events.

ADDITIONAL INFORMATION

Author contributions: Ya.P. Kireev, conceptualization, investigation, resources, data curation, writing original draft preparation; I.A. Mandel, investigation, resources, data curation, writing, review and editing; T.V. Klypa, conceptualization, visualization, data curation, supervision; D.S. Sungurova, investigation, resources, data curation; I.M. Yanovskaya, A.N. Shepelyuk, writing, review and editing. Thereby, all authors provided approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval: the study protocol was approved by the local ethics committee of Federal Research and Clinical Center of Specialized Medical Care and Medical Technologies FMBA of Russia (minutes of the meeting dated 13.09.2023). All study participants voluntarily signed an informed consent form before being included in the study.

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