Anesthesiological Support for Reconstructive Operations on the Aortic Arch: Nuances of Organoprotection

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Abstract--*This article considers the issues of anesthesia during operations on the aortic arch, and research on the topic under examination. It should be noted that operations on the aortic arch are one of the most complex surgical procedures.*

Key words*--antegrade perfusion of the brain; aneurysm of the aortic arch; circulatory arrest; hypothermia; protection from ischemia; prosthetics of the aortic arch; prosthetics of the ascending aorta.*

I. INTRODUCTION

The most difficult are operations on the arch of the heart in any surgical clinic. To date, there are no uniform, generally accepted protocols for conducting such interventions. For more than 20 years at the Russian Surgery Research Center in honor of academician B. V. Petrovsky the extensive experience in performing operations on the aortic arch has been accumulated. This allowed us to create our own protocols for anesthetic support and organoprotection, which allow us to perform reconstructive operations on the aortic arch effectively and safely. The center's developments have been repeatedly published in various scientific publications [1-3]. However, due to the complexity of the problems that the surgical team faced, many issues are still unresolved.

The best way to protect the brain and internal organs from ischemic damage during operations on the aortic arch is hypothermia with selective perfusion of the brain [4]. The same methods are indicated as the main methods of organoprotection in the recommendations for the diagnosis and treatment of patients with aortic pathologies [5].

Recently, antegrade brain perfusion (AP) has become the main method of selective brain perfusion [6]. The most optimal question is the choice of the volume speed of the AP. The volume rate of AP in most clinics is 10 ml per 1 kg of body weight [7, 8]. How much does this rate correspond to the actual need for oxygen in the brain and ensure the patient's safety? To assess the adequacy of AP, multi-modal monitoring of the state of the brain is required, which can help answer this question. The list of recommended monitoring methods is very wide, and there is no generally accepted standard to date [4].

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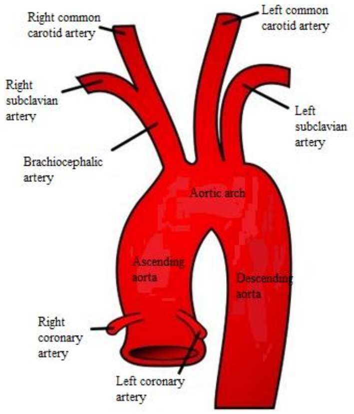

Fig. 1 –Aortic Arch

Due to the need for circulatory arrest (CA), temperature support for reconstructive interventions on the aortic arch plays an important role, which requires multi-channel monitoring and the use of effective methods of cooling and warming the patient. Recently, there is a distinct tendency to increase the CA temperature, the main one is moderate hypothermia (the Central temperature is 260C). The desire to increase the CA temperature is due to the negative consequences of deep hypothermia, the development of surgical technologies and the shortening of the time required for CA [6, 9].

Despite the large number of publications, there are still no strict recommendations for pharmacological protection of organs during operations with CA and AP. In this regard, pharmacological methods of protection against ischemia are in the last place in most organoprotection protocols, and clinics take into account their own understanding of the problem and accumulated experience [10].

II. RESEARCH OBJECTIVES

1) to make a differentiated choice of the volume rate of AP and examine its adequacy to the metabolic needs of the brain;
2) to evaluate the proposed mode of temperature support of the patient using combined (water and air) warming;
3) to consider the effectiveness of the selected protocol for protecting the brain and internal organs during reconstructive operations on the aortic arch.

III. MATERIAL AND METHODS

Operated in 2018-2019, 67 patients were selected and examined according to the proposed protocol. According to anthropometric parameters and age, the groups of patients were homogeneous (table. 1). All patients had the reduced physical status indicators according to the ASA classification (III-IV) and were classified as high anesthetic risk (IV according to the classification of Moscow Scientific Society of Anesthesiologists-Reanimatologists).

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Table 1 Anthropometric data and parameters of surgical interventions

Parameter	1st group	2nd group
Type of surgery	Reconstructive operations on the aortic arch	Reconstructive operations on the ascending aorta
Number of patients	33	34
Age, years	54±9,б (32-68)	59±11,0 (41-74)
Men/women	21/12	25/9
Duration of artificial circulation, min	178±59*	102±37
Duration of myocardial infarction, min	105±41*	81,6±35
Temperature of artificial circulation (central temperature, 0C)	26,4±2,4*	32,7±2,7
AP + CA, min	43±19,3	

Note. * -p < 0.05 between groups

Table 2 Intraoperative monitoring data

Parameter	Group	Outcome	Heparin	AC (beginning)	AC (middle)	AC (end)	Protamine
SctO2 (left side), %	1-я	73±6,5	68±4,0*	67±3,0*	68±6,0*	67±6,0	71±4,1
	2-я	72±4,3	69±3,5*	70±2,9*	69±4,3*	66±5,5	72±6,3
SctO2 (right side), %	1-я	71±5,1	65±6,8*	66±3,8*	66±5,6*	65±4,8*	71±5,2
	2-я	74±2,4	68±5,4*	69±3,1*	67±4,3*	67±5,0*	72±3,7**
Arterial blood lactate, mmol / l	1-я	0,7±0,3	0,8±0,3	1,0±0,4*, **	3 7±1 2*, **, #	2 7±1 3*, **, #	2,5±1,1*, #
	2-я	0,8±0,4	0,9±0,6	0,9±0,3*	1,0±0,4*	1,3±0,6*, **	1,6±0,8*, **
PvO2 (Central vein), mmHg. st.	1-я	40,0±5,0#	40,5±6,0#	53,0±10,0*, **	52,4±5,6*	42,4±7,3**	44,5±6,7*, #
	2-я	44,5±9,1	44,8±6,4	48±4,1	46,1±8,0	44,7±6,1	50,6±9,1*, **
StO2, %	1-я	77±9,0	69±7,3*	69±6,1*	67±5,2*	70±4,8*	76±6,8**

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	2-я	78±6,8	70±6,0*	69±11,2	69±11,2	69±9,2	73±7,4
Temperature, 0C: of bladder	1-я	36,3±0,6#	36,0±0,7	32,3±2,5*, **	30,5±3,8*, #	36,5±0,8**	36,2±0,5
	2-я	35,9±0,8	35,6±0,8	33,9±1,2*, **	33,7±1,4*	36,4±1,0**	36,0±0,4
Peripheral	1-я	30,7±2,9	33,4±2,4*	31,2±2,0**	30,1±3,1	32,3±1,2*, **	34 4±1 5*, **, #
	2-я	30,4±1,5	32,3±1,4*	32,2±1,3*	31,9±1,8*	32,1±1,4*	32,6±1,6*

Note. * - relative to the result, * * - relative to the previous stage, # - between groups of $p < 0.05$.

Patients of group 1 (n = 33) underwent reconstructive operations on the aortic arch (isolated and combined with aortic valve correction) under AP and CA (optimal Central temperature 26 oC). Patients of group 2 (n = 34) were operated on the ascending aorta (Bentall-DeBono, David, etc.) in AC conditions with moderate hypothermia (target Central temperature 32 oC). The team of surgeons and anesthesiologists was permanent. The time of AC and duration of myocardial ischemia were greater in group 1 patients.

All patients underwent balanced multicomponent anesthesia according to the center's method based on pro-pofol, midazolam, ketamine, fentanyl, and sevoflurane. Maintenance of myoplegia was performed by fractional administration of pipecuronium bromide. Myocardial protection was performed with a cardioplegic solution of Consol.

AP was performed through the right subclavian artery with the brachiocephalic trunk clamped and a balloon catheter in the left common carotid artery. AP was performed in mono- (n = 10) or bispheral (n = 23) mode, starting with a volume velocity (VV) of 10 ml / kg min. Transcranial dopplerography and cerebral oximetry were used to correct the VV and assess its adequacy, and also to determine the need to switch from mono - to bispheral AP.

Pharmacological protection during CA was performed using sodium thiopental (1 mg / kg), mannitol (0.7-1 g/kg), P-blockers, calcium channel blockers, corticosteroid hormones, mexidol, lidocaine, and others. During IC, ultradiafiltration was performed in group 1 patients.

IV. TRANSCRANIAL DOPPLEROGRAPHY.

Before the operation, the patients underwent duplex scanning of extracranial brachiocephal arteries, as well as transcranial duplex scanning of the arterial circle of Willis. Intraoperative Doppler examination was performed on the Angiodin-2K ultrasound diagnostic system (BIOS, Russia) using 2 MHz sensors. Intraoperational monitoring was conducted using a helmet, which in turn allows the sensors to be securely fixed. Two-channel bilateral monitoring of blood flow in the midbrain artery (MA) with automatic detection of microembolism was also performed. For natural circulation, the maximum systolic blood flow rate (Vs, cm/s) and the peripheral resistance index (PI) were estimated. In IC and AP, the maximum linear blood flow rate (Vm, cm/s) was estimated, which was maintained at least 20 cm/s [11]. As a result, we examined the symmetry of blood flow on both CMAS, allowing blood flow asymmetry of no more than 25%.

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Monitoring of regional oxygenation. In our work, a FORE-SlGHT™ laser tissue oximeter (CAS Medical System's™, USA) was used to evaluate cerebral (SrtO2) and tissue (StO) oxygenation. The device's sensors were located in the projection of the frontal lobe of the right and left hemispheres, as well as on the right forearm. The lower limit of the norm for FORE-SIGHT™is SrtO2 63-73% [12], and StO2 is less than 70% [13,14].

In some patients of group 1 (n = 10), the left side of the internal jugular vein bulb was catheterized.

Temperature monitoring. A water mattress Hico-Aquatherm 660 (Hitrz, Germany) was used to control body temperature in all patients. In group 1 patients, an air heating device Bair Hugger (3M, the USA) was additionally used with a mattress that was located under the patient. Warming of patients was started with admission to the operating room (target central temperature was 36oC) and continued until the beginning of IC. After the main stage during IC, patients were warmed in stages, in parallel with the temperature increase in the heat exchanger of the IC apparatus (the target central temperature was 36oC). The Central temperature was monitored in the bladder and nasopharynx. In addition, the peripheral temperature was monitored (the temperature sensor was located on the pad of the right index finger).

The test of indicators was carried out in the outcome, after the introduction of heparin, at the beginning, middle and end of IC, as well as 15 minutes after the introduction of protamine. Indicators were evaluated separately during AP (5, 15, and 30 minutes of AP, at the 34oc warming stage, and in 15 minutes after protamine administration).

Assessment of cognitive functions. In the preoperative period, on the 1st and 3rd postoperative days, patients underwent psychometric tests. To do this, we selected the clock-drawing test, the information-memory - concentration test, and the short-term visual memory test.

Clock drawing test. To perform the test, the patient is given a pencil and a blank sheet of unlined paper and asked to draw a round clock, put the numbers in the desired positions of the dial and draw arrows showing the specified time. A test score of less than 10 points indicates the presence of cognitive disorders [15].

Information-memory - concentration test. The test includes 24 questions and 2 tasks, including personal and non-personal memory. Each correct answer is estimated at one point, except for points where a different rating system is specified in points. The maximum score is 42; the lower the score- the more serious the memory and attention disorders [16].

Short-term visual memory test. During this test, subjects must memorize and then reproduce the maximum number of 12 numbers presented to them in the table for 20 seconds. Short-term visual memory was evaluated by the number of correctly reproduced numbers. The average level of test execution is 6-7 units [17].

The data are presented in the format M±SD, the differences were considered reliable at $p < 0.05$. Variance test (ANOVA) was performed, the Wilcoxon criterion for related samples, the student's criteria, and x2 were calculated.

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Table 3 data on AP monitoring in group 1 patients

Parameter	**Outcome**	**IC, 5 min**	**AP, 15 min**	**AP, 30 min**	**IC(warming till 34 degrees C)**	**15 min after protamine**
$SctO_2$ (left side), %	73±6,5	69±2,9	69±8,3	68±7,9	66±4,8*	71±4,1
$SctO_2$ (right side), %	71±5,1 67±4,7	67±4,7	68±5,0	67±5,6	67±5,8	72±3,7
Vs on the left SA, см/с	55,1±13,6	34,0±13*	28,8±10,2* **	25,6±8,2* **	40,6±17,5* **	59,2±11,6* **
Vs on the right SA, см/с	58,0±11,7	37,5±14,6 *	25,5+7,8 * **	26,5±7,0*	40,8±17,0* **	57,6±16,1**
Bulb of Internal jugular veins:						
Lactate (n=10), mol / l	0,6±0,2	1,2±0,4*	1,8±06* **	2,0±0,8* **	2,9±0,9*	2,6±1,1*
PvO_2 (n=10), мм рт.ст.	35,0±1,0	59,6±20,9 *	50,3±16,4*	51,0±15,3*	57,8±20,1*	48,8±16,8*
Temperature, ◦C: nasopharynx	36,2±0,8	32,4±2,7*	24,5±3,4 *	26,2±2,4*	34,9±1,1**	36,8±0,6**
Bladder	36,3±0,6	34,8±1,6*	29,1±2,9 * **	26,9±3,0*	32,6±2,2* **	36,2±0,5**

V. THE RESULTS OF THE EXAMINATION AND DISCUSSION

Examination of the effectiveness of antegrade perfusion and brain protection. Cerebral oximetry is the leading method for evaluating the effectiveness of AP in aortic arch operations in European clinics. More than 60% of hospitals use this method, while TCD is used much less frequently [4]. The examination of the obtained results showed that in patients of group 1 before the AP stage, as well as in patients of group 2 throughout the operation, there were no episodes of lower than normal SctO2 reduction (table. 2). However, in both groups, there was a decrease in SctO2 at the stage after heparin administration, during IC, and returned to the baseline level by the end of the operation. There was no pronounced interhemispheric asymmetry of cerebral oxygenation indicators.

Based on the simultaneous reduction of the SctO and Vs for the SMA, a decision was made about the insufficiency of the VV of AP and the need to increase it. Both methods in most cases reacted together (80% of

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observations). It is known that brain hyperperfusion is no less dangerous than hypoperfusion [7, 18]. Signs of hyperperfusion were determined mainly by TCD, the co in this respect was less informative: similar changes were detected in only 30% of cases. This is due to the fact that co is a more sensitive method for evaluating the decrease in oxygen delivery to tissues [19]. In 9% (3 patients), the transition to bispheral apgm was made after it was found that monospheral APGM was ineffective. Dynamic monitoring of co and TCD indicators allowed monitoring the adequacy of APGM, diagnosing cases of displacement or dislocation of balloon catheters, and avoiding blood flow asymmetry across the hemispheres.

Based on multi-modal monitoring data, the VV was dynamically changed. Due to this, during AP, the indicators of SctO2 and linear velocity in all patients were within the 'acceptable values' (table. 3). The VV varied from 5.8 to 16.5 ml / kg (average of 13.4±3.69 ml / kg). Blood test metabolites from the internal jugular veins bulb showed a sufficient level of oxygen delivery for the chosen method of brain protection (see table. 3). This method is not the main method for monitoring brain protection, since it allows only discrete assessment of oxygen transport and can only complement the methods of continuous monitoring. This determines its limited use in reconstructive operations on the aortic arch [4].

Patients with severe encephalopathy (both on the background of somatic disorders and isolated) were expected to be more in group 1 (8 vs. 2 patients; $p < 0.05$). However, the frequency of cases when encephalopathy was the leading symptom that determines the severity of the patient's condition, and the frequency of its manifestation against the background of somatic disorders did not differ between the groups (table. 4). Patients with severe encephalopathy were subsequently excluded from the examination of cognitive impairment.

The main focus of evaluating the effectiveness of the brain protection Protocol is on the examination of cognitive functions. The groups did not differ according to the results of psychometric tests (table. 5). The results of the "drawing hours" test in patients of both groups were lower on the 1st day after surgery and recovered to the initial level on the third day. The results of the information-memory-concentration test in patients of both groups were worse on the first day than in the outcome, and remained reduced on the third day. In group 2, they were improved on the third day. In both groups, the short-term memory test showed a deterioration on the first day after surgery, followed by an improvement on the third day. In group 1, the results remained reduced relative to the outcome. We would like to note that at all stages there were no differences between the compared groups of patients. When comparing the results of the psychometric tests between groups with antegrade mono-and Bi-sphere perfusion of the brain did not detect any differences. The results obtained indicate a sufficient level of brain protection in the implementation of the proposed Protocol.

The decrease in cognitive functions after operations on the ascending and aortic arches may be due not only to possible ischemic injuries, but also to a high level of microembolism in this type of intervention. Examinations conducted at the center have shown that the level of microembolism of the material in patients operated on the aorta is higher than in coronary artery bypass grafting. The material basis of these emboli is the micro aggregates of red blood cells [20].

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Table 4 Perioperative complications (% (and))

Complication	Group 1	Group 2
Circulatory collapse:		
intraoperative	45,5 (15)*	8,,8 (3)
In the intensive care unit	30,3 (10)	17,6 (6)
Heart failure: intraoperative		
In the intensive care unit	27,3 (9)	20,6 (7)
	21,2 (7)*	2,9 (1)
Respiratory failure	30 3 (10)*	17,6 (6)
Renal failure	12,1 (4)	2,9 (1)
Multiple organ failure	15,1(5)*	-
Coma	-	-
Encephalopathy:		
the leading symptom	6,1 (2)	-
on the background of somatic disorders	18,2 (6)	5,9 (2)
Hospital mortality	3 (1)	-

Note. * $p < 0.05$-between groups.

Table 5 results of psychometric tests

Test	Group	Outcome	1st day	3rd day
Clock drawing test	1	9,26±0,81	8,65±1,23*	8,91±1,2
	2	9,5±0,67	8,83±0,72*	9,25±0,87**
Information-memory test concentration of attention	1	28,56±5,38	24,97±5,41*	25,65±6,42*
	2	29,9±3,04	26,6±5,16*	27,7±4,8*,**
Short-term test memory	1	5,3±1,49	4,0±1,53*	4,64±1,62*,**
	2	5,67±1,97	4,17±2,29*	5,08±2,19**

Note. *- $p < 0.05$ relative to the outcome; * * - $p< 0.05$ between 1 and 3 days.

A debatable issue is the need for additional pharmacy protection with adequate AP and hypothermia, which is the main method of protecting the brain. Until now, it is not clear which drugs can actually help protect the brain from ischemia, due to the difficulty of collecting evidence. Too many different factors affect the patient, operations are performed in conditions of polypragmasia, so it is very difficult to distinguish the effects of individual substances, their protective effect. In this regard, Pharmacopoeia is the last place in the security protocols of the brain [10]. Nevertheless, the Protocol of our center includes a number of drugs with supposed

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protective properties, such as barbiturates, the effectiveness of which has recently been written by many authors [21]. This is largely due to the fact that in an emergency, the surgical team must be ready to perform full CA and deep hypothermia. In other words, the anesthesiologist needs to have some "stock" of cerebroprotection. In addition, despite the abundance of control methods, AP is a non-physiological condition in which additional protection will not be superfluous.

Temperature tracking. Effective temperature support is the key to ensuring the patient's safety during operations on the aortic arch. One of the most difficult issues is monitoring the Central temperature. The introduction of bladder temperature monitoring in our Department is due to the greater accuracy and less inertia of this method than the rectal temperature monitoring that we used earlier [22]. In both groups of patients, warming was started before the introduction of anesthesia. The use of air heating in addition to water heating made it possible to maintain a higher Central temperature in patients of group 1 already in the outcome (see table. 2.). Unintentional intraoperative hypothermia ($p < 0.05$) was more often registered in group 2 patients at this stage. A higher level of ru02 in group 2 patients than in group 1 patients indicated the presence of arteriovenous bypass surgery due to microvascular spasm.

Warming the patient before the upcoming cooling allows you to prevent temperature vasoconstriction and preserve the normal operation of the microvessels. This makes it possible to cool the patient quickly and with a lower temperature gradient. Before the start of IC, patients of both groups were sufficiently effectively warmed, which was manifested by the stability of the central and increase in peripheral temperature. In the post-fusion period, the central temperature in the groups did not differ, but the peripheral temperature was higher in the 1st group, which indicated a lower temperature gradient, uniform warming of the patient and better peripheral microcirculation. Indirectly, the violation of microcirculation in the 2nd group is indicated by higher indicators of ru02. Thus, the use of combined air and water heating allows you to warm the patient after CA more affectively.

It is quite difficult to interpret the results unambiguously. On the one hand, the described picture may be a manifestation of vascular insufficiency, which was more common during surgery in patients of group 1 and was a consequence of CA. On the other hand, this may be a sign of effective warming, which may contribute to Table 5 of moderate vascular insufficiency, since in ICU the frequency of this complication did not differ, and the dosages of vasopressors were minimal.

Warming the patient to the target temperature of 36oC allows to normalize hemostasis, reduce postoperative blood loss and reduce the frequency of resternotomies, and normalization of microcirculation contributes to faster wound healing and improves the results of surgical treatment [22].

Examination of the effectiveness of the Protocol for protecting internal organs during CA. The level of lactate during IC in both groups was higher than in the outcome, but was within normal values. After CA, there was a natural increase in lactate in group 1, but its indicators were not excessively high and fell within the limits acceptable for such interventions. At all stages of the operation, the pvO_2 level in both groups remained within the normal range. When entering the ICU, the lactate level in group 1 was higher than in group 2 (2.5±1.1 mmol / l versus 1.8±1.2 mmol/l; $p < 0.05$). However, after 6 hours there were no differences, which was due to an increase in the lactate level in group 2 from 1.8±1.2 to 3.1±1.0 mmol / l ($p < 0.05$). An increase in the level of lactate at this stage in patients operated on the ascending aorta indicated the recruitment of microcirculation against the background of warming and leaching of lactate from peripheral tissues. When examining the oxygen saturation of venous blood in the ICU, there was no difference between the groups.

A natural consequence of the transferred CA was a higher frequency of respiratory and multi-organ failure in group 1. The presence of such complications indicates a wide field for further work on the development of organ protective technologies during operations on the aortic arch. The frequency of renal failure requiring hemodialysis did not differ significantly, indicating sufficient protection of the kidneys. The cases of kidney failure registered in group 1 were caused by a large volume of blood loss and blood transfusion against the background of acute dissection (n = 1) and repeated interventions (n = 2), as well as the spread of aortic dissection to the visceral branches (n = 1). Vascular insufficiency was controlled in both groups with moderate doses of vasopressors, and its frequency differed only in the intraoperative period. Hospital mortality was 3% in group 1, and there were no deaths in group 2. The range and severity of postoperative complications indicate the effectiveness of the selected organoprotection Protocol. The key to success is a unified approach of the entire surgical team to the protection of internal organs and the brain.

VI. CONCLUSION

1. The proposed additions to the organ protection Protocol for operations on the aortic arch can improve the results of surgical treatment of patients with aortic arch pathology.
2. The combined use of cerebral oximetry and transcranial dopplerography allows us to assess the adequacy of oxygen delivery to metabolism in the brain during antegrade perfusion.
3. The simultaneous use of these techniques allows to maintain the speed of antegrade cerebral perfusion and to determine the choice of its option (bi-, mono- sphered).
4. Effective temperature tracking requires multi-channel monitoring of the Central temperature, a combination of air and water heating of the patient during the operation.

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