Postoperative cognitive dysfunctions after cardiac surgery: the role of neurosurgery and cardiology

Disfunciones cognitivas postoperatorias tras cirugía cardíaca: el papel de la neurocirugía y la cardiología

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Abstract

Postoperative cognitive dysfunction (POCD) is one of the key problems faced by patients after cardiac surgery, including coronary bypass surgery and heart valve surgery. POCD manifests itself in the form of disorders of memory, attention, executive functions and other aspects of cognitive activity, which significantly reduces the quality of life of patients and complicates rehabilitation.

The authors set a number of tasks in their work: to consider the pathophysiological mechanisms underlying POCD, including ischemic brain damage, microembolism, inflammatory response and metabolic changes, as well as to study the features of an interdisciplinary approach to the diagnosis and treatment of POCD, combining the efforts of cardiologists, neurosurgeons and specialists in neurorehabilitation.

The role of cardiology in the context of the issue under consideration is to prevent intraoperative complications, monitor cardiovascular function, and minimize the risk of strokes and hypoperfusion. Neurosurgery and neuromonitoring ensure the timely detection and correction of neurological complications, as well as the development of methods to protect the brain during surgery.

The authors explore modern technologies such as intraoperative imaging, the use of neuroprotective drugs, and rehabilitation strategies aimed at restoring cognitive functions. Attention is paid to the prospects of personalized medicine and the importance of further research to optimize the treatment and prevention of POCD.

Keywords: postoperative cognitive dysfunctions, cardiac surgery, neurosurgery, cardiology, cognitive rehabilitation, neuroprotection.

Resumen

La disfunción cognitiva postoperatoria (DCPO) es uno de los problemas clave que enfrentan los pacientes después de una cirugía cardíaca, incluida la cirugía de bypass coronario y la cirugía de válvulas cardíacas. La DCPO se manifiesta en forma de trastornos de la memoria, la atención, las funciones ejecutivas y otros aspectos de la actividad cognitiva, lo que reduce significativamente la calidad de vida de los pacientes y complica la rehabilitación.

Los autores establecieron una serie de tareas en su trabajo: considerar los mecanismos fisiopatológicos subyacentes a la DCPO, incluido el daño cerebral isquémico, la microembolia, la respuesta inflamatoria y los cambios metabólicos, así como estudiar las características de un enfoque interdisciplinario para el diagnóstico y tratamiento de la DCPO, combinando los esfuerzos de cardiólogos, neurocirujanos y especialistas en neurorrehabilitación.

El papel de la cardiología en el contexto del tema en consideración es prevenir las complicaciones intraoperatorias, monitorear la función cardiovascular y minimizar el riesgo de accidentes cerebrovasculares e hipoperfusión. La neurocirugía y la neuromonitorización garantizan la detección y corrección oportunas de las complicaciones neurológicas, así como el desarrollo de métodos para proteger el cerebro durante la cirugía. Los autores exploran tecnologías modernas como la obtención de imágenes intraoperatorias, el uso de fármacos neuroprotectores y las estrategias de rehabilitación destinadas a restablecer las funciones cognitivas. Se presta atención a las perspectivas de la medicina personalizada y a la importancia de realizar más investigaciones para optimizar el tratamiento y la prevención de las disfunciones cognitivas posoperatorias.

Palabras clave: disfunciones cognitivas posoperatorias, cirugía cardíaca, neurocirugía, cardiología, rehabilitación cognitiva, neuroprotección.

Introduction

Postoperative cognitive dysfunction (POCD) is a common complication that occurs in patients after cardiac surgery[1]. The frequency of their occurrence varies from 20% to 80%, depending on the diagnostic methods, the nature of the operation and the individual characteristics of the patient. These disorders may have temporary manifestations or be of a long-term nature, having a negative impact on the quality of life, social activity and the rehabilitation process.

The main causes of POCD are considered to be ischemic brain damage associated with hypoperfusion, microembolism, and inflammatory reactions that occur during and after surgery. Additional risk factors are the patient's age, concomitant cardiovascular diseases, and a history of neurological pathologies[2].

In this regard, the urgency of the problem of POCD is due to the need for an interdisciplinary approach combining the efforts of specialists in the field of cardiology, neurosurgery, anesthesiology and rehabilitation. Cardiologists play a key role in preventing intraoperative complications and managing cardiovascular risks, while neurosurgeons and neurologists ensure timely diagnosis and development of neuroprotective strategies.

The purpose of this study is to analyze the mechanisms of the development of POCD, to evaluate the contribution of cardiology and neurosurgery to their prevention and treatment, as well as to consider modern methods of diagnosis and rehabilitation of cognitive impairments.

Materials and methods

The topic of postoperative cognitive dysfunctions (POCD) after cardiac surgery is quite relevant, for this reason, there are a significant number of publications in this area by specialists in the field under study. During the preparation of the work, the selection and systematization of scientific publications on the topic of POCD, including data from cardiology, neurosurgery, anesthesiology and neurorehabilitation over the past 15 years, was carried out. Based on the analysis of these sources, modern clinical recommendations and protocols for the treatment of POCD were studied, as well as the features of the historical development of approaches to the diagnosis and treatment of cognitive dysfunctions.

The comparative analysis made it possible to compare various cardiac surgical procedures (for example, with and without an artificial circulatory system) and their effects on cognitive functions, as well as approaches to the diagnosis of POCD, including neuropsychological testing, instrumental methods (MRI, CT, electroencephalography) and biomarkers.

The authors carried out a classification of risk factors for the development of POCD (age, preoperative status, type of surgery, etc.), systematized the mechanisms affecting the development of cognitive impairment (ischemia, inflammation, neurotoxicity), compared various strategies for the treatment and prevention of POCD. Hypotheses have also been developed about the interaction of brain and cardiovascular systems under surgical stress and the construction of a model of the pathophysiological mechanisms of POCD development. The possibilities of using data on risk factors to predict the likelihood of developing POCD in patients are demonstrated.

Results

Postoperative cognitive dysfunctions (POCD) develop as a result of the complex interaction of many factors that cause changes in the brain at the structural, functional, and molecular levels[3]. This condition often occurs after patients undergo heart surgery and has important implications for acute and long-term clinical outcomes and the patient's quality of life. Patients with atherosclerotic cardiovascular disease have an increased risk of developing cognitive impairment or dementia simply as a concomitant disease of their primary pathological process. Researchers note that approximately 40-50% of patients who have undergone heart surgery develop POCD in the early postoperative period[4].

The main mechanisms contributing to the development of POCD are ischemic brain damage, microembolism, inflammatory response, and metabolic changes.

Table 1. The main pathophysiological mechanisms of postoperative cognitive dysfunctions (POCD), their causes and consequences

The mechanism of occurrence of POCD	Causes of POCD occurrence	Consequences of the occurrence of POCD
Ischemic brain damage	- hypoperfusion of the brain due to hypotension or inadequate perfusion in ACS;	- apoptosis of neurons;
Microembolism	- ingestion of air or fat emboli into the cerebral vessels;	- impaired synapse function;
Inflammatory response	- tissue fragments (e.g. calcinates);	- local cerebral infarctions;
Metabolic changes	- activation of the complement system due to blood contact with AIS;	- occlusion of small vessels of the brain;
Oxidative stress	- cytokine storm (IL-6, TNF-α, IL-1β);	- lacunar heart attacks;
Violation of autophagy	- hypoglycemia or hyperglycemia during surgery;	- temporary cognitive impairment;

Ischemic brain damage plays a key role in the development of POCD. This mechanism is caused by a decrease in cerebral blood flow during cardiac surgery, especially when using an artificial circulatory system (ACS). During operations with AIS, temporary hypoperfusion of the brain is observed, which leads to insufficient supply of oxygen and nutrients to the tissues.

Ischemia causes a cascade of pathological processes[5]. First of all, the neurons that are most sensitive to lack of

oxygen suffer. Decreased blood flow leads to impaired aerobic metabolism and increased lactate levels, which contributes to the development of acidosis in brain tissues. These changes activate the mechanisms of cellular apoptosis and necrosis, which leads to the loss of neurons.

In addition, brain ischemia leads to a malfunction of the blood-brain barrier (BBB), which makes brain tissues vulnerable to the penetration of toxic substances from the blood[6]. Local heart attacks and ischemic hypoxia zones contribute to the formation of cognitive impairments, such as decreased memory, attention, and executive functions.

A particular danger is the combination of ischemia with subsequent reperfusion - restoration of blood flow, which can increase damage due to the formation of reactive oxygen species (ROS) and oxidative stress. Reperfusion is often accompanied by neuroinflammation, which exacerbates cognitive consequences.

Microembolisms are one of the important pathophysiological mechanisms of the development of postoperative cognitive dysfunctions (POCD). They occur when emboli, such as air bubbles, fat droplets, or fragments of atherosclerotic plaques, enter the bloodstream and block small vessels in the brain. Such emboli can form both during the operation itself and in the postoperative period.

One of the most dangerous sources of microembolism is manipulations related to artificial blood circulation devices, such as valve surgery or coronary bypass surgery. During such operations, air, fat droplets, or microfragments from atherosclerotic plaques can enter the arteries supplying the brain[7]. These emboli, passing through small vessels, can lead to their occlusion, disrupting normal blood flow in certain areas of the brain.

Blockage of small vessels causes microinfarcts – the so-called lacunar infarcts, which may be insignificant at the structural level, but serious in terms of functional disorders. These microinfarcts are mainly localized in subcortical areas of the brain, which can impair cognitive functions such as memory, attention, and decision-making abilities. In addition, microembolisms can be the cause of neuroinflammation, as small vascular lesions activate the immune response and inflammatory reactions in the brain, which further increases ischemic damage to neurons and reduces neuroplasticity, which also contributes to cognitive impairment.

The inflammatory response is one of the significant mechanisms contributing to the development of POCD. This process is activated after cardiac surgery and is accompanied by the release of cytokines and other inflammatory mediators that can have a damaging effect on the brain. After cardiac surgery, the complement system is activated, which contributes to the inflammatory process[8]. When blood interacts with artificial materials in the AIS, such as tubes and catheters, complement activation occurs, which triggers a cascade of inflammation that leads to the release of pro-inflammatory cytokines such as interleukin-6 (IL-6), tumor necrosis factor alpha (TNF-α) and interleukin-1 beta (IL-1b), which play a key role in the development of neuroinflammation[9].

Neuroinflammation in the brain can cause damage to neuronal structures, impaired BBB function, which increases the permeability to toxic substances and cellular elements that can enhance brain damage. Inflammation also leads to increased vascular permeability, brain edema, and increased intracerebral pressure[10]. Such processes, in turn, disrupt normal neural activity and can cause cognitive impairments such as problems with memory, concentration, and decreased executive functions. One of the most dangerous aspects of the inflammatory response is its ability to enhance pre-existing ischemic and microembolic lesions[11]. Inflammation can make the brain more susceptible to hypoxia and microinfarctions, which only exacerbates postoperative cognitive dysfunctions.

Metabolic changes occurring during and after cardiac surgery also play an important role in the development of POCD. They can affect several key processes, including energy metabolism, blood glucose levels, electrolyte balance, and mitochondrial function, which can lead to neuron damage and cognitive impairment.

One of the most important metabolic factors is hypoglycemia or hyperglycemia, which can occur during surgery, especially if the patient is under anesthesia or artificial blood circulation[12]. Fluctuations in blood glucose levels can have a negative effect on brain cells, especially on neurons, which are extremely sensitive to changes in energy balance. Lack of glucose (hypoglycemia) can disrupt the normal functioning of neuronal cells, reducing their ability to maintain synaptic activity and transmission of nerve impulses. On the contrary, elevated glucose levels (hyperglycemia) can lead to activation of inflammatory processes, impaired microcirculation and increased oxidative stress, which contributes to damage to neurons.

An imbalance of electrolytes (for example, calcium, magnesium, and potassium) is also an important metabolic factor affecting the development of cognitive impairment[13]. Special attention should be paid to the metabolism of mitochondria, as they are the main source of energy for brain cells. Mitochondrial dysfunction can lead to the accumulation of metabolic products such as free radicals, which cause oxidative damage to cells. Oxidative stress resulting from mitochondrial dysfunction can activate the pathways of apoptosis (programmed cell death) and damage the structures of brain cells, including DNA, proteins and lipids, which, in turn, leads to deterioration of cognitive functions.

Metabolic changes can also affect the acid-base balance in the body, which disrupts the normal functioning of neurons and contributes to their damage. This is especially

important in the context of cardiac surgery, when patients are often exposed to changes in blood pH levels, which can have long-term effects on the brain.

Oxidative stress is an important pathophysiological mechanism that plays a central role in the development of POCD after cardiac surgery. In the context of cardiac surgery, oxidative stress often occurs as a result of ischemia and reperfusion[14]. When blood flow is restored after a period of hypoperfusion, for example, when using an artificial circulatory system, there is a sharp increase in the formation of free radicals such as superoxide and hydrogen peroxide. Such molecules can damage cell membranes and mitochondria, disrupting energy metabolism and leading to the activation of inflammatory processes in the brain[15]. A sudden change in oxygen levels also promotes the synthesis of new RFCs, increasing metabolic and inflammatory damage that accelerates the development of cognitive disorders.

Oxidative stress is also associated with the activation of inflammatory processes. Free radicals formed during oxidative reactions can stimulate the release of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor alpha (TNF-α)[16]. This situation, in turn, can cause neuroinflammation, damage to cell membranes, and increased neuronal dysfunction, which ultimately impairs patients' cognitive abilities after surgery. In addition, oxidative stress can disrupt vascular function, increasing the permeability of the blood-brain barrier (BBB). This allows toxic molecules to enter the brain, exacerbating ischemic and inflammatory damage. BBB dysfunction also contributes to deterioration of neuronal activity and decreased neuroplasticity.

During cardiac surgery, especially when using an artificial circulatory system, the brain is exposed to a number of stress factors, including hypoxia, ischemia, and inflammation[17]. These factors can disrupt the normal functioning of the autophagic system. For example, with hypoxia and ischemia, there is a lack of oxygen and nutrients, which affects the energy balance of cells and slows down the processes of autophagy. As a result, damaged or excess cellular components, such as accumulated proteins, mitochondria, and other organelles, are not removed in a timely manner, which contributes to their accumulation and disruption of normal cellular function.

Violation of autophagy can also lead to increased inflammatory processes, since accumulated damaged cell components activate immune responses[18]. For example, the aggregation of proteins such as tau and amyloid can initiate the activation of microglia, cells of the brain's immune system, which leads to neuroinflammation and damage to neurons. In addition, the accumulation of mitochondria that have not gone through the normal processes of autophagy can lead to disruption of mitochondrial metabolism and increased oxidative stress, which further exacerbates cognitive dysfunctions.

It is important to note that autophagy plays a key role in maintaining neuroplasticity, the brain's ability to adapt to changes and restore normal function after injury, so disruption of this process can reduce the brain's ability to recover from surgery and accelerate the development of cognitive impairments such as problems with memory, attention, and executive functions.

It is necessary to inform patients and their relatives about the risks of stroke and POCD before any cardiovascular surgery[19]. There are several clinical predictors of POCD. These include the burden of atherosclerotic cardiovascular diseases, old age, diabetes, depression, heart failure, a history of stroke, carotid artery stenosis, and underlying cognitive impairment. A recent study has shown that the preoperative gene expression profile can help predict postoperative POCD[20]. This can be a useful tool to guide risk discussions before surgery in addition to other clinical risk factors.

An analysis of the literature has shown that the development of postoperative cognitive dysfunctions is associated with multicomponent disorders resulting from the interaction of the brain and the cardiovascular system during surgical stress. Based on the results of a number of studies, hypotheses have been formulated about the interaction of the brain and the cardiovascular system under surgical stress (Table 2).

Table 2. Hypotheses about the interaction of the brain and the cardiovascular system under surgical stress

Hypothesis	Mechanism	Results
Hypothesis 1. Hemodynamic disorders as a trigger of cognitive dysfunctions	1. Intraoperative hypotension and decreased cardiac output decrease cerebral blood flow.	Cognitive impairment, especially in patients with chronic cardiovascular diseases.
Hypothesis 2. The effect of systemic inflammation on neuroinflammation	2. Hypoperfusion causes energy deficiency in neurons and local hypoxia.	An increased inflammatory cascade in the brain leads to the progression of cognitive impairment.
Hypothesis 3. The role of oxidative stress and mitochondrial disorders	1. The release of pro-inflammatory cytokines (IL-6, TNF-α) activates microglia through disruption of the blood-brain barrier.	Damage to neurons reduces the efficiency of signal transmission, which affects cognitive functions.
Hypothesis 4. Imbalance of the autonomic nervous system	2 Cytokines cause direct damage to neurons and inhibit neurogenesis.	Postoperative cognitive dysfunctions become more pronounced in patients with low heart rate variability.

Further, the hypotheses were integrated into a single model (Table 3).

Table 3. Integrating hypotheses into a single model

Stage	Description of the hypothesis	Mechanisms of interaction	Clinical consequences
1. Initiation of surgical stress	Surgical trauma causes the release of cortisol, adrenaline, and norepinephrine through activation of the HPA axis.	1. Activation of the sympathetic nervous system (SNS).	1. Tachycardia, hypertension.
2. Systemic inflammation	Surgical trauma activates pro-inflammatory cytokines (IL-6, TNF-α, IL-1β).	2. Increased systemic inflammation.	2. Increased vascular tone.
3. Impaired cerebral blood flow	Hypoperfusion due to intraoperative hypotension, vasoconstriction, or decreased cardiac output.	1. Increased permeability of the blood-brain barrier (BBB).	1. Neuro-inflammation.
4. Oxidative stress	Hypoxia and inflammation increase the production of reactive oxygen species (ROS).	2. Migration of immune cells to the brain.	2. Increased oxidative stress in brain tissues.
5. Neurotransmitter imbalance	Hypoxia disrupts the synthesis of acetylcholine, dopamine, and serotonin.	1. Brain hypoxia, decreased oxygen delivery.	1. Energy deficit of neurons.
6. The formation of the POCD	The complex effects of inflammation, hypoxia, oxidative stress, and neurotransmitter imbalance.	2. Activation of hypoxic-induced factors (HIF).	2. Metabolic disorders.

The development of a model explaining the mechanism of their occurrence is based on the interaction of various factors such as surgical stress, inflammation, hypoxia, oxidative stress and neurotransmitter imbalance. In this detailed analysis, we will look at how these processes interact and influence the development of cognitive impairments in patients.

At the stage of the onset of surgical stress, the hypothalamus-pituitary-adrenal axis is activated in the body, which leads to the release of stress hormones such as cortisol, adrenaline and norepinephrine. Such hormones trigger a reaction of the sympathetic nervous system, which contributes to an increase in vascular tone and an increase in blood pressure. This is a normal physiological reaction of the body to stress, however, prolonged or excessive exposure to stress factors may cause an overload of the cardiovascular system. In patients with existing heart and vascular diseases, this can worsen the condition, creating additional stress on the body.

In addition, activation of the sympathetic nervous system leads to increased systemic inflammation, which becomes a key factor in the development of POCD[21]. Inflammation stimulates the immune system and causes the release of pro-inflammatory cytokines such as IL-6, TNF-α and IL-1β. Such molecules are signals that promote the activation of inflammatory processes in the body, including in the brain, which directly affects cognitive functions.

One of the most important mechanisms playing a role in the development of POCD is systemic inflammation[22]. During surgery, inflammation is activated at the whole-body level, and pro-inflammatory cytokines can enter the brain, disrupting the integrity of the BBB, which allows inflammatory molecules to affect neurons, causing neuroinflammation. Neuroinflammation, in turn, leads to a decrease in neuroplasticity and a deterioration in the function of neurons.

Cytokines such as IL-6 and TNF-α have a direct toxic effect on neurons, which disrupts their normal functioning. This can manifest itself in the form of cognitive impairments, such as impaired memory, attention, and other aspects of cognitive function. Inflammation also causes increased oxidative stress in the brain, which leads to damage to cells and tissues, exacerbating the pathological process[23].

The next important factor contributing to the development of POCD is a violation of cerebral blood flow, which can occur due to hypoperfusion of the brain. Surgical stress, especially in conditions of hypotension or vasoconstriction, may decrease blood flow to the brain, leading to hypoxia of neurons. Lack of oxygen in the brain disrupts its metabolism, and despite the body's compensatory mechanisms, the brain finds itself in a state of oxygen starvation.

Hypoxia activates hypoxic-induced factors (HIF) that try to compensate for oxygen deficiency, but if this process continues for a long time, it leads to metabolic disorders in neurons, a decrease in their energy supply and, as a result, their damage and death. Such changes can cause deterioration of cognitive functions such as attention, memory, and learning ability.

One of the consequences of hypoxia and inflammation is increased oxidative stress[24]. Hypoxia and inflammation contribute to an increase in the production of reactive oxygen species (ROS), which are highly reactive and damage cellular structures, including the membranes of neurons and mitochondria. Mitochondria play a key role in the energy metabolism of cells, and their damage leads to energy deficiency, which impairs the functioning of neurons.

When mitochondria lose their functionality, this leads to accelerated apoptosis (cell death) of neurons, which is directly related to the deterioration of cognitive abilities. Damage to the membranes of brain cells also reduces their ability to repair, impairing neuroplasticity and learning and memory abilities.

Hypoxia and inflammation not only disrupt the structure of brain cells, but also alter the balance of neurotransmit-

ters, chemicals that transmit signals between neurons. For example, hypoxia reduces the synthesis of acetylcholine, dopamine, and serotonin, which is crucial for cognitive processes. Acetylcholine plays an important role in memory and learning, dopamine in motivation and attention, and serotonin in emotional stability.

Disruption of the activity of these neurotransmitter systems leads to a decrease in cognitive functions such as attention, memory, orientation, and problem-solving abilities. Patients may experience not only physical weakness, but also psychoemotional disorders such as depression and anxiety.

The combined effect of all the above–mentioned factors –inflammation, hypoxia, oxidative stress, and an imbalance of neurotransmitters - leads to the accumulation of damage in neural networks[25]. The chronic effects of these factors on the brain contribute to the development of POCD. Decreased neuroplasticity, decreased synapse density, and impaired neurogenesis (the formation of new neurons) impair the brain's ability to recover and adapt.

Clinically, this manifests itself in the form of various cognitive disorders, such as decreased memory, attention, problem-solving ability, orientation in space and time. Such disorders can be both temporary (in the acute postoperative period) and persistent, which requires long-term recovery and specialized treatment.

Based on the model presented above, key risk factors and their impact on POCD were identified (Table 4).

Table 4. Key risk factors and their impact on POCD

The risk factor	Mechanism	Clinical manifestations
Age > 65 years	Decreased neuroplasticity, increased BBB permeability.	Increased risk of cognitive impairment.
Chronic hypertension	Decreased reserve of cerebral blood flow.	The risk of hypoperfusion during surgical stress.
Prolonged surgery (> 3 hours)	Increased inflammatory response, decreased hemodynamics.	Hypoxia and oxidative stress.
Elevated cytokine levels (IL-6, TNF-α)	Activation of microglia and inflammation in the brain.	Impaired memory, attention, and orientation.
Brain hypoperfusion	Energy deficiency in neurons.	Cognitive decline.
Previous cognitive impairments	Weakened compensatory potential of neural networks.	Deterioration of existing cognitive functions.

Each of the presented factors has an impact through various pathophysiological processes. Age over 65 leads to a decrease in neuroplasticity and an increase in the permeability of the blood-brain barrier, which increases the risk of cognitive impairment. Chronic hypertension reduces cerebral blood flow, increasing the likelihood of hypoperfusion during surgery, which also affects cognitive function.

Prolonged surgery increases inflammation, reduces hemodynamics, and can lead to hypoxia, which damages neurons and impairs cognitive abilities. Elevated cytokine levels activate neuroinflammation, which disrupts memory, attention, and orientation.

Hypoperfusion of the brain causes an energy deficit of neurons and reduces cognitive functions. In patients with previous cognitive impairments, the compensatory mechanisms of the brain are weakened, which contributes to the progression of cognitive disorders after surgery[26].

The mechanisms of development of POCD include a complex interaction between surgical stress, inflammation, hypoxia, oxidative stress, and changes in neurotransmitter activity. These processes lead to structural and functional changes in the brain that impair the patient's cognitive functions. Models of the pathophysiology of POCD help to better understand how and why such disorders occur, which is important for developing effective prevention and treatment methods.

Discussion. Experts point out that in order to prevent the occurrence of POCD, it is necessary to minimize risk factors, and this directly depends on the actions of the surgical team. These actions may include: avoiding prolonged intubation, using heparin-coated tubes for artificial blood circulation, and maintaining adequate blood flow during artificial blood circulation by maintaining the average arterial pressure on artificial blood circulation above the lower limit of cerebral autoregulation. In addition, POCD can be prevented by proper intraoperative blood glucose monitoring, slow warming after hypothermia and avoiding hyperthermia, avoiding excessive manipulation of the aorta and multiple episodes of aortic compression, proper monitoring of cerebral oximetry and relief of hypoxia[27]. In addition, preoperative risk factors for POCD should be considered: diabetes, underlying anemia, and carotid artery stenosis. Another approach is to initiate a postoperative cognitive assessment program: in this case, patients are assessed with the help of physiotherapy to assess their functional state before discharge and, if necessary, they are placed on outpatient registration. This type of rehabilitation can prevent the possible development of POCD in the short and long term.

However, the most important aspect minimizing the risks of POCD is the interaction of neurosurgeons and cardiologists (Table 5).

Table 5. Key aspects of interaction between neurosurgeons and cardiologists in the prevention and treatment of postoperative cognitive dysfunctions		
Role-playing activities	Neurosurgeons	Cardiologists
Patient preparation	Assessment of the risk of neurological complications, diagnosis of existing neurological diseases.	Assessment of the patient's cardiovascular condition, treatment of chronic heart diseases (coronary artery disease, hypertension, heart failure).
Monitoring during the operation	Monitoring of cerebral circulation, diagnosis of ischemic changes and microembolism.	Joint work with anesthesiologists to maintain the stability of the cardiovascular system, control blood circulation and oxygen levels in the blood.
Postoperative follow-up	Diagnosis of neurological changes using neuroimaging (MRI, CT), neuroprotection and rehabilitation management.	Monitoring of hemodynamics, glucose levels, electrolytes, prevention of thrombosis and myocardial infarction.
Neuroprotection	Development and implementation of a neuroprotection strategy (the use of neurostimulators, antioxidants).	Maintaining optimal blood pressure, oxygen delivery, and metabolism, which helps prevent brain damage.
Early intervention	Early diagnosis and treatment of microinfarcts, strokes, assessment of neurological changes using MRI and CT.	Early correction of cardiac risks, heart rhythm management and anticoagulant therapy to prevent thrombosis and cerebral ischemia.
Rehabilitation	Interaction with neuropsychologists and rehabilitologists to restore cognitive functions, monitoring cognitive impairments.	Joint work with rehabilitologists to restore functional abilities and control cardiac parameters.

Preparing a patient for cardiac surgery is a critically important step, during which both the cardiovascular and neurobiological aspects of the patient's condition must be taken into account. At this stage, special attention is paid to both the physical and psychological state of the patient, since cardiac surgery can have a significant impact on brain functioning, especially in the postoperative period[28]. The role of the cardiologist and neurosurgeon at the training stage is to conduct a comprehensive assessment of the patient's condition and take the necessary measures to minimize the risks of postoperative cognitive disorders.

The cardiologist conducts a comprehensive examination of the patient to assess the general condition of the cardiovascular system and identify any chronic diseases such as coronary heart disease, hypertension or heart failure that may complicate the course of surgery. It is important that the cardiologist eliminate or minimize the risks associated with these conditions before starting surgery. An example of such measures may be optimization of blood pressure, regulation of cholesterol and blood sugar levels, as well as the use of drugs to stabilize the heart rate. All these actions reduce the likelihood of cardiogenic complications such as myocardial infarction, cardiac arrhythmias and hypoxemia, which can have a negative effect on cerebral circulation and increase the risk of cognitive impairment.

On the other hand, neurosurgeons play an important role in assessing a patient's neuropsychological condition, identifying possible neurological disorders that may worsen after surgery. For example, if a patient has previously experienced mild cognitive impairments such as memory or concentration problems, a neurosurgeon may suggest additional studies using neuroimaging techniques such as MRI or CT to rule out hidden pathologies such as ischemia or microinfarcts of the brain. It is important to assess the condition of the central nervous system in order to understand how much it is at risk due to possible changes in blood circulation that may occur during cardiac surgery[29].

Patient preparation also includes discussing with the patient the possible risks and complications associated with surgery, including the consequences for cognitive functions. The patient's psychological state plays an important role in the recovery process, and any anxiety or stress reactions can exacerbate postoperative cognitive disorders. Cardiologists and neurosurgeons should work closely with psychologists and psychiatrists to reduce the patient's stress level, prepare him for surgery and minimize the psychological burden, which in turn can help reduce the risk of developing POCD.

Monitoring the patient's condition during cardiac surgery, especially with the use of an artificial circulatory system (ACS), is one of the most critical aspects for preventing the development of postoperative cognitive dysfunctions (POCD). During this period, the interaction of cardiologists and neurosurgeons becomes especially important, since heart surgery and vascular interventions can significantly affect cerebral circulation and neurophysiological processes. The interaction of these specialists is aimed at minimizing the risks of ischemia, hypoxia and microembolism, which can damage the brain and contribute to cognitive disorders in the postoperative period.

Cardiologists are responsible for maintaining stable functioning of the cardiovascular system during surgery, which includes monitoring blood pressure, oxygen saturation, maintaining a normal heart rhythm, as well

as monitoring circulatory parameters such as cardiac output and venous pressure. Any fluctuations in these parameters can lead to insufficient blood supply to the brain, which in turn contributes to the occurrence of ischemia and damage to neurons. Cardiologists work closely with anesthesiologists to monitor carbon dioxide, oxygen, and other vital parameters, ensuring optimal oxygen supply to tissues and organs, including the brain.

An important part of a cardiologist's job is also to monitor the use of an artificial circulatory system, which can alter normal blood flow and, consequently, affect the cerebral blood supply. Establishing and maintaining optimal hemodynamic levels while working on AIC helps to avoid critical episodes of brain hypoperfusion, which can lead to microinfarctions and other injuries. This is especially important to prevent neuropsychological consequences such as postoperative cognitive disorders.

Neurosurgeons, in turn, play a key role in monitoring the patient's brain condition during surgery. They actively monitor the state of cerebral circulation using special techniques and devices. For example, neurosurgeons can use cerebral oxygen monitoring technologies (such as transcranial dopplerography or rebound oxygen monitoring) to detect any signs of ischemia or insufficient blood supply to the brain in a timely manner. Timely detection of these disorders allows immediate measures to be taken to correct them, for example, by changing blood circulation parameters or using medications that improve microcirculation in the brain[30].

In addition, neurosurgeons can use neuroimaging techniques such as intraoperative ultrasound diagnostics or monitoring of brain electrical activity to assess the condition of neural structures and respond quickly to any abnormalities. If microembolisms or disorders of cerebral circulation are detected, neurosurgeons can make adjustments during surgery to minimize damage to brain tissue and reduce the risk of developing cognitive disorders in the future.

Postoperative follow-up of a patient undergoing cardiac surgery is a crucial stage at which neurosurgeons and cardiologists play key roles in the prevention and treatment of postoperative cognitive dysfunction (POCD). During this period, it is important not only to monitor the patient's physical condition, but also to closely monitor his neurological condition in order to detect any signs of cognitive disorders or other neurological complications in time.

The role of cardiologists in postoperative follow-up is to constantly monitor the function of the cardiovascular system and other physiological parameters that may affect cerebral circulation. They provide monitoring of blood pressure, heart rate, oxygen and carbon dioxide levels in the blood, as well as checking the normalization of metabolic processes such as glucose and electrolyte levels. Constant monitoring of these indicators is critical, since any fluctuations can lead to hypoperfusion of the brain, which, in turn, increases the risk of POCD.

The cardiologist pays special attention to the patient's condition in the first hours and days after surgery. The reason for this situation is as follows: during this period, cardiogenic complications such as hypotension, cardiac arrhythmia, or recurrent myocardial infarction are most likely, which can contribute to deterioration of cerebral circulation and lead to cognitive disorders. Cardiologists also continue to monitor hemodynamic parameters and can adjust therapy, including anticoagulant and antiplatelet therapy, which is important to prevent the formation of blood clots and microembolisms that can cause microinfarcts in the brain.

Neurosurgeons, in turn, are engaged in the assessment and correction of possible neurological disorders in the postoperative period. This includes regular checkups of the patient to identify cognitive, motor, or sensory impairments. Neurosurgeons actively use neuroimaging techniques such as MRI or CT to identify microinfarcts, microembolisms, or other pathological changes in the brain that can cause cognitive disorders. If damage is detected, neurosurgeons develop a treatment plan aimed at minimizing the consequences and restoring the patient's neuropsychological functions.

In addition, neurosurgeons can apply neuroprotection methods, such as the use of antioxidant drugs, neurostimulators or other pharmacological agents aimed at restoring the normal functioning of neurons and minimizing inflammatory processes in the brain. Such measures help to improve the recovery of cognitive functions and reduce the risk of deterioration in the long term.

Postoperative follow-up also includes work with rehabilitologists and psychotherapists. It is important to note that cardiologists and neurosurgeons can actively collaborate with these specialists to create a comprehensive rehabilitation program aimed at restoring both the cardiological and cognitive functions of the patient. For example, postoperative physical activity and cognitive training, as well as psychological support for the patient, are of great importance for restoring normal neuropsychological activity.

Neurosurgeons can also recommend cognitive rehabilitation programs aimed at improving memory, attention, and other cognitive functions that may be impaired by surgery. In this context, it is important that cardiologists and neurosurgeons jointly monitor the results of treatment and adjust therapeutic approaches depending on the patient's condition.

Neuroprotection, as a key element of the strategy for preventing postoperative cognitive dysfunction (POCD), includes a set of measures aimed at minimizing brain damage resulting from cardiac surgery. In this area, the interaction of cardiologists and neurosurgeons is of great importance, as each of the specialists brings their own knowledge and approaches, which significantly reduces the risk of neuropathological changes that can lead to cognitive disorders.

The role of cardiologists in neuroprotection is to optimize the patient's cardiovascular system, which directly affects the blood supply to the brain. Cardiologists are involved in regulating the patient's hemodynamics both before and during surgery, as well as in the postoperative period. One of the most important aspects is to ensure adequate blood flow, especially when using an artificial circulatory system, which can disrupt the normal perfusion of the brain and endanger its cells. To prevent these risks, cardiologists monitor blood pressure, blood oxygen levels, heart rate, and other parameters that may affect cerebral circulation.

The cardiologist also prescribes medications that help maintain an optimal vascular system, such as antihypertensive agents, anticoagulants, or antiplatelet agents. This is necessary to prevent the formation of blood clots, which can block the blood supply to the brain and cause microinfarctions or microembolisms. Thus, cardiologists provide favorable conditions for normalization of microcirculation in the brain and prevention of its damage as a result of disorders of the cardiovascular system.

Neurosurgeons, in turn, play an important role in neuroprotection during surgery and in the postoperative period. They use various techniques to minimize brain damage caused by surgery and can apply neuroprotective drugs such as antioxidants that help protect neurons from damage caused by oxidative stress and inflammation. This helps to reduce the degree of ischemia and inflammation, contributing to the preservation of normal brain function.

In addition, neurosurgeons are actively using neuroimaging technologies and monitoring of cerebral circulation, which makes it possible to detect early signs of ischemia or other disorders of the blood supply to the brain. Modern methods such as transcranial Dopplerography, as well as monitoring oxygen in brain tissues, allow you to quickly respond to any changes and adjust the parameters of the operation to minimize the risks of brain damage. The above is especially important in the postoperative period, when cerebral perfusion may be weakened, which increases the likelihood of developing POCD.

Neurosurgeons can also use neurostimulation or neuroplasticity techniques that help stimulate neuron repair and promote neuroregeneration. Such methods may be useful for restoring cognitive functions such as memory, attention, and learning ability, which may be impaired in the postoperative period.

Long-term follow-up and rehabilitation after cardiac surgery play a key role in preventing the development and minimizing the consequences of postoperative cognitive dysfunction (POCD). During this phase, patients begin to return to normal life, but their brain health and cardiovascular system require careful monitoring and support. The role of neurosurgeons and cardiologists at this stage is to provide comprehensive rehabilitation aimed at restoring cognitive functions and maintaining stability of the cardiovascular system, which reduces the risk of further cognitive impairment.

Conclusions

Postoperative cognitive dysfunction (POCD) is a serious problem that can significantly impair the quality of life of patients undergoing cardiac surgery. The development of POCD can be caused by various pathophysiological mechanisms, including ischemic brain damage, microembolism, inflammatory reactions, and metabolic changes, which requires an interdisciplinary approach to diagnosis, prevention, and treatment. In this context, the joint efforts of cardiologists and neurosurgeons, which ensure comprehensive and effective patient management, are of particular importance.

The role of cardiologists is to maintain stable cardiovascular function of the patient during the postoperative period. Monitoring of blood pressure, oxygen levels, and heart rate, as well as the use of anticoagulant and antiplatelet therapy, play an important role in preventing cardiogenic complications such as hypotension, microembolism, and thrombosis, which can lead to impaired cerebral circulation and the development of POCD.

The role of neurosurgeons is to perform diagnostics and neuroprotection aimed at preventing and minimizing brain damage. The use of modern methods of neuroimaging, monitoring of cerebral circulation and neuroprotective therapy helps in the early detection of neurological disorders and their correction at the earliest stages. This reduces the likelihood of developing persistent cognitive disorders and promotes the restoration of neuropsychological functions.

Interdisciplinary interaction between neurosurgeons, cardiologists, and other specialists (rehabilitologists, psychotherapists) is an essential component in the rehabilitation and postoperative follow-up process. The joint work of these specialists provides an integrated approach, including both treatment and rehabilitation, which contributes to better recovery and reduces the risk of developing POCD.

References

1. Colak, Z. Borojevic, M. Bogovic, A. Influence of intraoperative cerebral oximetry monitoring on neurocognitive function after coronary artery bypass surgery: a randomized, prospective study Eur J Cardiothorac Surg. 2015; 47:447-454

2. Relander, K. Hietanen, M. Rantanen, K. Postoperative cognitive

change after cardiac surgery predicts long-term cognitive outcome Brain Behav. 2020; 10:e01750

3. Merino J., Latour L., Tso A., Lee K., Kang D., Davis L., et al. Blood-brain barrier disruption after cardiac surgery. Am J Neuroradiol. 2013. 34:518–23.

4. Caldas JR., Haunton VJ., Panerai RB., Robinson TG., Hajjar LA.. Cerebral autoregulation in cardiopulmonary bypass surgery: a systematic review. Interact Cardiovasc Thorac Surg. 2018. 26:494–503.

5. Mangla R., Kolar B., Almast J., Ekholm SE. Border zone infarcts: pathophysiologic and imaging characteristics. Radiographics. 2011. 31:1201–14.

6. Kiabi FH., Soleimani A., Habibi MR. Neuroprotective effect of low mean arterial pressure on postoperative cognitive deficit attenuated by prolonged coronary artery bypass time: a meta-analysis. Braz J Cardiovasc Surg. 2019. 34:739–48.

7. Patel N., Banahan C., Janus J., Horsfield MA., Cox A., Marshall D., et al. Neurological impact of emboli during adult cardiac surgery. J Neurol Sci. 2020 416:117006.

8. Lewis, C. Levine, A. Balmert, L.C. Neurocognitive, quality of life, and behavioral outcomes for patients with covert stroke after cardiac surgery: exploratory analysis of data from a prospectively randomized trial Anesth Analg. 2021; 133:1187-1196

9. Miniksar, Ö.H. Çiçekçioğlu, F. Kılıç, M. Decreased brain-derived neurotrophic factor levels may predict early perioperative neurocognitive disorder in patients undergoing coronary artery bypass surgery: a prospective observational pilot study J Clin Anesth. 2021; 71:110235

10. Bukauskienė, R. Širvinskas, E. Lenkutis, T. The influence of blood flow velocity changes to postoperative cognitive dysfunction development in patients undergoing heart surgery with cardiopulmonary bypass Perfusion. 2020; 35:672-679

11. Rawlings, A.M. Sharrett, A.R. Albert, M.S. The association of late-life diabetes status and hyperglycemia with incident mild cognitive impairment and dementia: the ARIC Study Diabetes Care. 2019; 42:1248-1254

12. Scrimgeour, L.A. Ikeda, I. Sellke, N.C. Glycemic control is not associated with neurocognitive decline after cardiac surgery J Card Surg. 2022; 37:138-147

13. Sabe, A.A. Dalal, R.S. Chu, L.M. Preoperative gene expression may be associated with neurocognitive decline after cardiopulmonary bypass J Thorac Cardiovasc Surg. 2015; 149:613-623

14. Shayan, S. Okocha, O. Srdanovic, N. Preoperative anemia and risk for perioperative neurocognitive dysfunction in cardiac surgery patients: a retrospective analysis J Cardiothorac Vasc Anesth. 2022; 36:1056-1063

15. Uysal, S. Lin, H.M. Trinh, M. Optimizing cerebral oxygenation in cardiac surgery: a randomized controlled trial examining neurocognitive and perioperative outcomes J Thorac Cardiovasc Surg. 2020; 159:943-953.e3

16. Tsai, H.H. Yen, R.F. Lin, C.L. Increased risk of dementia in patients hospitalized with acute kidney injury: a nationwide population-based cohort study PLoS One. 2017; 12:e0171671

17. Giang, K.W. Jeppsson, A. Karlsson, M. The risk of dementia after coronary artery bypass grafting in relation to age and sex Alzheimers Dement. 2021; 17:1042-1050

18. Evered L., Silbert B., Scott DA., Knopman DS., Knopman D., DeKosky ST., et al. Recommendations for the nomenclature of cognitive change associated with anaesthesia and surgery-2018. Anesthesiology. 2018. 129: 872–9.

19. Daiello LA., Racine AM., Yun Gou R., Marcantonio ER., Xie Z., Kunze LJ., et al. Postoperative delirium and postoperative cognitive dysfunction: overlap and divergence. Anesthesiology. 2019. 131:477–91.

20. Bartels K., Li Y-J., Li Y-W., White WD., Laskowitz DT., Kertai MD., et al. Apolipoprotein epsilon 4 genotype is associated with less improvement in cognitive function five years after cardiac surgery: a retrospective cohort study. Can J Anaesth. 2015. 62:618–26.

21. Greaves D., Ross TJ., Ghezzi ES., Keage HAD., Psaltis PJ., Davis DHJ., et al. Risk factors for delirium and cognitive decline following coronary artery bypass grafting surgery: a systematic review and meta-analysis. J Am Heart Assoc. 2020.9:e017275.

22. Toledo, C. Andrade, D.C. Díaz, H.S. Neurocognitive disorders in heart failure: novel pathophysiological mechanisms underpinning memory loss and learning impairment. Mol Neurobiol. 2019; 56:8035-8051

23. Chung, H.E. Chen, J. Ghosalkar, D. Aortic valve calcification is associated with future cognitive impairment J Alzheimers Dis Rep. 2021; 5:337-343

24. Patel, N. Banahan, C. Janus, J. Neurological impact of emboli during adult cardiac surgery J Neurol Sci. 2020; 416:117006

25. Lachmann G., Feinkohl I., Borchers F., Ottens TH., Nathoe HM., Sauer A-M., et al. Diabetes, but not hypertension and obesity, is associated with postoperative cognitive dysfunction. Dement Geriatr Cogn Disord. 2018. 46:193–206.

26. Liu J., Huang K., Zhu B., Zhou B., Ahmad Harb AK., Liu L., et al. Neuropsychological tests in post-operative cognitive dysfunction: methods and applications. Front Psychol. 2021. 12:2047.

27. Klinger RY., Cooter M., Bisanar T., Terrando N., Berger M., Podgoreanu MV., et al. Intravenous lidocaine does not improve neurologic outcomes after cardiac surgery: a randomized controlled trial. Anesthesiology. 2019. 130:958–70.

28. Boone MD., Sites B., von Recklinghausen FM., Mueller A., Taenzer AH., Shaefi S.. Economic burden of postoperative neurocognitive disorders among us medicare patients. JAMA Netw Open. 2020. 3:e208931.

29. Terrando N., Yang T., Wang X., Fang J., Cao M., Andersson U., et al. Systemic HMGB1 neutralization prevents postoperative neurocognitive dysfunction in aged rats. Front Immunol. (2016) 7:441.

30. Vasunilashorn S., Marcantonio E. Cytokines and postoperative delirium in older patients undergoing major elective surgery. Alzheimers Dement. 2015. 11(7 Suppl. 1):211.