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CLINICAL STUDY

Features of gas exchange and metabolism of the brain during revascularization of the carotid arteries

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ABSTRACT
The relevance of the stated topic of scientific research is determined by the fact that stroke is still the most important medical and social problem both in the world as a whole and in the Republic of Kazakhstan in particular due to high rates of morbidity, mortality, and disability. In addition, cerebrovascular diseases occupy one of the leading places in the structure of morbidity, disability and mortality, second only to coronary heart disease in Kazakhstan as well as around the world. The purpose of this research work is to study the features of gas exchange and brain metabolism during the revascularization of the carotid arteries. The basis of the methodological approach in this research work is a combination of methods of systematic analysis of the main features of gas exchange and brain metabolism in combination with a systematic study of the results obtained during the treatment of patients diagnosed with carotid artery stenosis at the Syzganov National Research Surgery Center in the period 2015–2020, divided into two main groups according to the applied principles of treatment. The results obtained in this research work indicate high efficiency of carotid endarterectomy and carotid stenting in finding ways to solve problems with cerebral circulation in patients suffering from carotid artery stenosis, as well as with the need for further use of these methods in clinical practice. The results obtained in the course of this scientific study, as well as the conclusions formulated on their basis, are of significant practical importance in terms of creating effective methods for treatment of patients recovering after a stroke, as well as for prevention of occurrence and development of stroke *(Tab. 4, Ref. 22)*. Text in PDF *www.elis.sk*
KEY WORDS**:** carotid artery stenting, carotid endarterectomy, ischemic stroke, atherosclerosis, heart attack.

Introduction

Numerous scientific studies performed in clinical settings over the past 20 years have demonstrated that the technique of carotid endarterectomy (CEE) in combination with the use of medications significantly reduces the risk of stroke and enhances long-term survival after surgery. Numerous scientific studies conducted in this direction serve as a clear demonstration of the fact that in symptomatic patients with carotid artery narrowing from 70–99 % or 50–69 %, the risk of stroke or death within five years after CEE is reduced by 16 % or 8 %, respectively, while in asymptomatic patients with stenosis of 60–99 %, it drops by 5 %. Consideration should be given to the fact that CEE is only preferred if the requirements defined by the American Heart Association Carotid Endarterectomy Committee (Caplan et al, 2017) are met. In accordance with these requirements, the incidence of homolateral stroke after surgery should not exceed 3 % in asymptomatic patients, 5 % in patients with a transient ischemic attack (TIA), and 7 % in patients after stroke. The overall fatality rate for all groups should not exceed 2 %.

According to the accumulated practical experience, the methods of carotid endarterectomy are mostly effective in the treatment of stenotic lesions of the internal carotid arteries (ICA). At the same time, in everyday medical practice, it is a clear evidence of the fact that the majority of patients have simultaneous lesions of several arterial basins, which in some cases contributes to the worsening of the prognosis and, in principle, casts doubt on the feasibility of the surgical intervention, since in this case, the risk of surgery may be higher than its potential benefits (Grotta et al, 2021). The factors that notably increase the risk of complications (Baimbetov et al, 2018,2020) after surgery include occlusion of the contralateral carotid artery, history of ipsilateral carotid endarterectomy, as well as various types of damage to the carotid and coronary arteries. It should be noted that among the key problems in the rehabilitation of patients after carotid endarterectomy, are those with unstable coronary circulation in patients with coronary heart disease (CHD) occurring against the background of the un-

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derlying disease. The list of the key risk factors for complications after surgery should include angina pectoris of degree III–IV, damage to the coronary arteries in combination with problems of the trunk of the left coronary artery, as well as left ventricular ejection fraction below the norm of 40 %.

The conducted laboratory and practical studies indicate that coronary artery lesions were diagnosed in 61 % of patients who underwent ICA stenting during coronary angiography (Simone et al, 2016). Only 39 % of patients showed clinical symptoms of coronary heart disease. Vascular lesions in combination with stenosis of the trunk of the left coronary artery were detected in 17 %, 15 %, 22 %, and 7 % of the examined patients, respectively. In these patients, hemodynamic instability during surgery can be a key cause of myocardial infarction. The currently used diagnostic measures aimed at identifying problems with the coronary arteries and allowing timely determination of the degree of risk of surgical intervention make it possible to reduce the overall incidence of postoperative complications. According to the data obtained from the literature, the frequency of postoperative complications during CEE is in range from 3.9 % to 8.9 %, in certain situations reaching 13 %. Carotid stenting in patients with ischemic heart disease (IHD) has several advantages over internal carotid endarterectomy (Sidawy and Perler, 2018). Endovascular intervention should be considered a minimally invasive procedure because it does not require general anesthesia. All of these features make it possible to avoid the potential hemodynamic instability associated with general anesthesia, as well as allows reducing blood loss, which in turn, significantly reduces the risk of death and complications in patients diagnosed with coronary heart disease (Malhorta and Gandhi, 2021; Texakalidis et al, 2018; Lima et al, 2016).

The main goal of this research work is a practical study of the features of gas exchange and brain metabolism during carotid revascularization, which is of significant practical importance in the recovery of a patient after a stroke, as well as in matters of its prevention.

Materials and methods

The research methodology is based on the analysis of the results of surgical treatment of 113 patients with carotid artery stenosis who were treated at the Syzganov National Research Surgery Center from 2015 to June 2020. All patients were conditionally divided into two basic groups according to the established method of treatment. In the group of carotid endarterectomy, 58 operations were performed, while in the group of carotid stenting, 55 surgical interventions were carried out for stenting the internal carotid artery. The presented statistical analysis includes the results of 113 episodes of surgical interventions. In the course of this scientific study, the criteria applied for the inclusion of patients in the study were as follows:

- Carotid stenosis over 60 % in combination with previous transient ischemic attacks or amaurosis fugax,
- Encephalopathy,
- Ischemic stroke, which was transferred at an earlier time,
- Embolic atherosclerotic plaques,
- Stenosis of the carotid arteries over 70 % in the absence of clinical signs of chronic cerebrovascular insufficiency and general stability of embolic atherosclerotic plaques.

This study did not include patients with conditions as follows:

- Restenosis as a result of carotid endarterectomy or carotid stenting,
- Large-scale lesion of the vertebrobasilar basin (mainly vertebral and subclavian arteries),
- History of extra-intracranial microanastomosis on the side of occlusion,
- Complex heart rhythm problems (atrial fibrillation, atrial and ventricular fibrillation and flutter),
- Severe respiratory problems,
- Problems of cardiac activity of functional class iii–iv.

In addition, patients who had contraindications to any of the applied methods of treatment (acute coronary syndrome, or hemodynamically significant tortuosity or kinking of the target carotid artery, and severe atherosclerotic plaque calcification) were not included in the study. In order to test the null hypothesis regarding the homogeneity of patients, differences in gender, age (Tab. 3), as well as in comorbidities (Tab. 2) were studied in the study groups according to Student's t-test. Thus, the methodology of this research work is a combination of theoretical and practical approaches to the consideration of issues raised in the subject of this scientific research, while using a previously prepared theoretical base of this scientific research, systematizing the results obtained, and presenting the obtained numerical values in special tables. The theoretical basis of this research work is founded on available publications of researchers devoted to the practical study of issues related to the characteristics of gas exchange and brain metabolism during carotid revascularization and to a number of other related topics. The theoretical research base prepared in this way serves as a reliable foundation for further practical scientific research in the direction indicated in the subject of this scientific work.

A practical study of the results obtained during the treatment of patients diagnosed with carotid artery stenosis at the Syzganov National Research Surgery Center in the period 2015–2020, were divided into two main groups according to the applied principles of treatment. In addition, at this stage of the research work under consideration, the preliminary results obtained during the study were analyzed and compared with the results and conclusions of other researchers involved in the analytical and practical developments of the problematic issues included in the subject of this scientific research as well as of related matters. Such a comparison contributes to the most objective reflection of the conducted scientific research, as well as to obtaining a qualitative final picture of the study of the characteristics of gas exchange and brain metabolism during revascularization of the carotid arteries. The results obtained during the study formed the basis for formulating final conclusions which sum up the entire complex of scientific research performed and serve as their logical reflection.

Results

Our scientific study of the features of gas exchange and metabolism of the brain during revascularization of the carotid arteries

Tab. 1. Neuro-specific biomarkers of damage to tissues of the central nervous system.

Biomarkers	Origin	Function	Clinical use
Protein S100B	Produced by astrocytes	Calcium binding protein is involved in the cell cycle of proliferation and differentiation	Diagnostics (40, 41) Infarct volume (42, 43) Stroke severity (42, 43, 44) Hemorrhagic transformation (45)
Glial fibrillary acidic protein - GFAP	Produced by astrocytes, hepatocytes	The structural element of blood-brain barrier cells	Diagnostics (46, 47)
Neuron-specific enolase - NSE	Produced by neurons. Produced in neuroblastoma, uremia	Neuronal glycolysis enzyme	Diagnostics (41) Infarct volume (42) Stroke severity (48)
N-methyl-D-aspartate receptor Antibodies-NMDA-RAb	NMDA receptors are found only in the brain and are involved in the development of glutamate-mediated excitotoxicity underlying cerebral ischemia	Autoantibodies to NR2A/NR2B subunits of the NMDA receptor – during ischemia, peptide fragments of the NMD A receptor break off, appear in the bloodstream and cause an immune response	Diagnostics (49, 50) Stroke severity (49, 50)
Myelin-basic protein - MBP	Produced by oligodendrocytes, Schwann cells when myelin is damaged	Myelination of neuronal structures of the central and peripheral nervous system	Diagnostics (47) Infarct volume (43) Stroke severity (43)
Brain natriuretic peptide - BNP	Synthesized in vascular endothelium and brain structures	Pro-adrenergic action by direct stimulation of sympathetic nerve endings	Risk of stroke (51,52 Cardioembolic stroke (53)

Tab. 2. The frequency of comorbidities in patients in the CEE and CAS groups.

Identified diseases	CEE group	CAS group	p
IHD (%)	51 (59.3%)	52 (62.6%)	0.94
Functional class of angina pectoris 1 or 2 (%)	51 (59.3%)	52 (62.6%	0.94
Functional class of angina above 3 (%)	15 (17.4%)	21 (25.3%)	0.26
History of myocardial infarction (%)	12 (13.9%)	15 (18.1%)	0.53
Arterial hypertension (%)	58 (100%)	55 (100%)	0.99
Arrhythmias (%)	11 (12.7%)	15 (18.1%) j	0.39
Chronic lower-limb ischemia (%)	32 (36.1%)	35 (40.9%)	0.87
Type II diabetes (%)	13 (13.9%)	11 (12.0%)	0.82

Tab. 3. The ratio of patient groups by sex, age, and number of operations performed.

Characteristic	CEE	CAS	p
Total number of patients	58	55	–
Number of operations, n	58 (100%)	55 (100%)	–
Operations performed on men (%)	51 (87.9%)	50(90.9%)	
Operations performed on women (%)	7 (12.0%)	5 (9.0%)	
Age, years	–	–	–
Average +–M	64.69 ± 6.89	65.20 ± 9.24	0,68
Range, years	50–77	40–83	–
Patients under 75	77 (90.7%)	72 (87.9%)	0.62
Patients over 75 years of age (%)	8 (9.3%)	10 (12.1%)	0.62

gave us the following results. More than ten international randomized evidence-based studies have been conducted in order to determine the effectiveness and safety rates of stenting of the internal carotid arteries and compare them with the those of carotid endarterectomy. However, some of them are in conflict with each other, confirming the advantage of either carotid stenting (*SAPPHIRE*) or carotid endarterectomy *(EVA-3S*); while some studies see these two treatments as being equivalent *(CAVATAS, SPACE, CREST)*. During revascularization operations on the internal carotid arteries, a reperfusion syndrome develops, which undoubtedly leads to a change in brain metabolism, damage to the endothelium and activation of coagulation factors, stasis, and hypercoagulation, no-reflow phenomenon (syndrome of non-resumption of blood flow), which can lead to thrombosis in the reconstruction area and worsen ischemia up to the level of necrosis (Moore, 2018). Dysfunction of the blood-brain barrier is evident after reperfusion. The appearance of inadequate barrier permeability promotes the penetration of neuro-specific proteins into the blood. All these factors can lead to cerebral edema and clinically manifest as encephalopathy syndrome. Due to the inconclusiveness of studies evaluating the two methods of revascularization of the internal carotid arteries, i.e, of carotid endarterectomy and carotid stenting, there is a need for further study of brain metabolism and gas exchange, along with the study of neuro-specific biomarkers of central nervous system tissue damage. This scientific study was carried out using the following main objects:

1. Group A is comprised of patients with symptomatic and asymptomatic clinically significant carotid stenoses who are indicated for carotid endarterectomy.
2. Group B is comprised of patients with symptomatic and asymptomatic clinically significant carotid stenoses who are indicated for internal carotid stenting.
3. Group C is comprised of healthy people.

The scientific research is carried out at Almaty, Syzganov National Research Surgery Center, Department of Vascular Surgery. Cerebral oximetry enables to assess the local saturation of the brain tissue with oxygen in order to detect as early as possible the cases of both symmetric and asymmetric forms of cerebral hypoperfusion, even at moments of critical compression. Table 1 presents data on a possible assessment of the degree of damage to the tissue of the central nervous system in patients of the first two groups.

The analysis of the above research data allows us to highlight both the strengths and weaknesses of the treatment outcome, both

Tab. 4. Comparative parameters of arterial blood gas exchange in number of patients.

Patient	Age	Diagnosis at admission	I			II			III			IV		
			1	2	3	1	2	3	1	2	3	1	2	3
1	69	Atherosclerosis, Takayasu's syndrome, hemodynamically significant stenosis of the left ICA 75%, stenosis of the right ICA 50%	7.32	42.8	40.9	7.3	43.0	39.6	7.3	36.4	143	7.3	46.1	42.8
2	65	Atherosclerosis, Takayasu's syndrome, hemodynamically significant stenosis of the left ICA 65%, stenosis of the right ICA 40%	7.3	42.9	41	7.3	31	40	7.3	31	202	7.3	44	42
3	58	Atherosclerosis, Takayasu syndrome, subocclusion of the right ICA, hemodynamically insignificant stenosis of the left ICA 25%, chronic cerebrovascular insufficiency of degree II	7.3	46.1	29.0	7.3	39.7	42.2	7.3	32.6	159	7.2	56.2	26.9
4	68	Atherosclerosis, Takayasu syndrome, subocclusion of the right ICA, hemodynamically insignificant stenosis of the left ICA 25%, chronic cerebrovascular insufficiency of degree II	7.2	46.7	30.0	7.3	40.6	37.3	7.3	36.7	85.8	7.2	45.7	34.2
5	58	Atherosclerosis, Takayasu syndrome, hemodynamically significant narrowing of the left ICA 75%, chronic cerebrovascular insufficiency of degree II	7.3	45.9	37.8	7.3	38.9	50.5	7.3	26.9	162	7.2	47.1	39.4

in carotid endarterectomy and in stenting of the internal carotid artery (Jhaveri, 2020). Due to the ambiguous conclusions of studies, and in strict accordance with the positions of evidence-based medicine, there is a clear need for further studies of brain metabolism and gas exchange, as well as studies of neuro-specific biomarkers of tissue damage in the main parts of the central nervous system by comparing data obtained as a result of the practical application of two methods of surgical treatment. Table 2 presents the incidence of concomitant diseases in patients belonging to the CEE and CAS groups (carotid angioplasty and stenting).

In order to assess the functional classes of *angina pectoris*, the classification of the Canadian Heart Association was used, while the assessment of the class of heart failure was performed according to the classification of the New York Heart Association, while the assessing of the severity of chronic ischemia of the lower extremities, the Fontaine-Pokrovsky classification was used. Table 3 presents data on the ratio of patient groups per gender, age, and number of operations performed.

Table 4 presents comparative values of arterial blood gases of some patients who participated in the study. Conventional symbols: pH/blood gases; I – after induction from the superior bulb of the superior jugular vein; II – after induction from the central venous catheter: III – after induction from the radial artery; IV – 3 minutes after clamping the ICA from the superior bulb of the superior jugular vein. 1 – pH, 2 – pCO_2 (mmHg), 3 – pO_2 (mmHg).

As follows from the presented data, the pH value in all patients is slightly below normal (7.35–7.45), which is evidence of some shift in the acid-base balance towards an increase in acidity (acidosis). The pCO2 values are also predominantly reduced, while the pO_2 values are higher than the normative ones. The t-criterion is determined based on the ratio as follows:

$$t = \frac{M_1 - M_2}{\sqrt{\frac{P_{12}}{N_1} + \frac{P_{22}}{N_2}}} \quad (1)$$

where: N_1 is the number of patients in the carotid stenting group; N_2 is the number of patients in the carotid endarterectomy group; P_{12} – standard deviation of the first sample of patients P_{22} – standard deviation of the second sample of patients; M_1 is the arithmetic mean of the first sample of patients; M_2 is the arithmetic mean of the second sample of patients.

Regarding age differences, $t_в = 65.2–64.69/\sqrt{1.55232} + 0.8184844828 = 0.331224$. With regard to differences in the frequency of comorbidities, $t_п = 32\text{-}30.375/\sqrt{7.272727} + 6.896551 = 0.431697$. With regard to gender differences and number of operations performed, $t_{оп} = 29–27.5/\sqrt{2.364574} + 3.456942 = 0.621689$. Since in all cases, the criterion $t < 1$, the null hypothesis of the homogeneity of the studied groups of patients can be considered correct. Thus, the confirmation that these groups belong to a single general population has been obtained.

When summarizing the results of the performed scientific studies, it can be stated that against the background of the initial syndrome of mild cognitive impairment in the immediate postoperative period in groups 1 and 2, postoperative coronary dysfunction developed, which was most pronounced in the second group, while the results of neuropsychological testing in Group 3 remained at baseline. However, already a month after the surgical treatment, positive dynamics were noticed in all groups, indicating an almost complete elimination of cognitive deficits. Thus, based on the results of the neuropsychological testing, it can be concluded that a significant impairment in cognitive functions developed in the period after the surgical intervention. In the third group of relatively healthy people, no significant impairment of cognitive functions was detected throughout the entire period of the study, which cannot be said about the patients from the other two groups. At the same time, the presence of initial exertional angina of any functional class in patients should be considered the main risk factor for the occurrence of significant complications for carotid endarterectomy. No significant cardiovascular risk factors have been identified for carotid stenting (Ringer, 2018).

The appropriate candidates for carrying out carotid endarterectomy are patients who have passed the stage of six months after the stroke (late recovery period) and have the diagnosis of carotid artery occlusion, patients not older than 75 years in need of temporary internal shunting, and patients with cardiac pathology, namely with primary *angina pectoris* up to the second functional class. In patients without surface damage by ulceration, the best conditions for carotid stenting are when isoechoic, homogeneous or heterogeneous hyperechoic atherosclerotic plaque is present. As studies have shown, in patients of the first two groups, significant improvements in their general condition were observed after carotid endarterectomy and stenting of the internal carotid artery, while tangible results were achieved in the treatment of cerebral circulatory disorders in patients from both groups. At the same time, the general condition of the patients was significantly worse than that of the people in the third experimental group. There were no significant differences in the general condition of patients in the first two experimental groups. In this context, it should be noted that the risk of occurrence and development of complications in both cases can be considered insignificant, which determines significant prospects for further practical use of carotid endarterectomy and stenting of the internal carotid artery in prevention and treatment of diseases caused by stenosis of the carotid arteries, which is an important aspect in terms of expanding the possibilities of clinical practice in the treatment of this type of disease.

Discussion

To date, in addition to studying the causes and methods of treating coronary heart disease, the classification of the severity of strokes are the most relevant issues in terms of assessing statistical data on the increase in mortality rates among the population suffering from this disease. The existing classification of neurological complications after cardiac surgery includes an acute cerebrovascular accident combined with delirium and postoperative cognitive dysfunction. The main reasons for this state of affairs may lie in microembolization of cerebral vessels, cerebral hypoperfusion, and neuroinflammation (Putanov et al, 2018). Carotid endarterectomy is a highly effective intervention aimed at repeated prevention of stroke in patients with clinical manifestations of carotid artery stenosis, as well as in those with asymptomatic stroke. At the same time, it is well known that carotid endarterectomy can be expressed in transient disorders of blood flow in the brain, as well as problems in oxygen transport, which is caused by a combination of a number of interrelated factors and can be expressed in bilateral and asymmetric cerebral hypoperfusion. The main triggers of postoperative cerebral hypoperfusion are blood flow disorders in combination with cerebral atherogenic embolism. In this context, complications of carotid endarterectomies such as transient hypo- and hyperperfusion disorders of cerebral circulation can lead to irreversible consequences, expressed in dysfunctions of both hemispheres of the brain (Obraztsov et al, 2017).

In patients suffering from vascular dementia at the initial stage, especially in the elderly, carotid endarterectomy can slow down the progression of cognitive dysfunction due to the steady restoration of impaired blood flow in the brain. At the same time, at an early stage of the postoperative period, complications in the form of a stroke, various bleedings, and malfunctions of the cardiovascular system are possible. Regional anesthesia has certain advantages, while in the majority of cases, carotid endarterectomy is performed under general anesthesia. The most common approaches to the use of general anesthesia for carotid endarterectomy consider general intravenous anesthesia using propofol and inhalation anesthesia with sevoflurane. It is widely believed that these anesthetics have pronounced cerebroprotective properties and are capable of qualitatively lowering cerebral blood flow and oxygen use, while also reducing the release of markers of neuronal damage, largely due to pharmacological preconditioning. At the same time, some studies focusing on comparing the effect of propofol and sevoflurane on the results of carotid endarterectomy have very conflicting results, ranging from the relatively favorable effects of using these components to the clear advantages of inhalation-type anesthesia (Giannopoulos et al, 2018).

Medical practice in different countries of the world indicates the presence of numerous cases of practical application of regional anesthesia for anesthetic management of carotid endarterectomy. Opinions are expressed regarding the positioning of this type of anesthesia as an alternative to general anesthesia, while among the undoubted advantages of this technique, the possibility of implementing the simplest and most effective dynamic neuromonitoring is invariably noted. Against this background, arguments regarding the safety of using this technique among patients with a concomitant diagnosis of coronary heart disease, hypertension, and cardiac arrhythmias look unconvincing. Inhalation anesthesia with sevoflurane, due to the properties that distinguish this drug, also provides a reliable cardioprotective effect. The conducted studies do not provide statistical information on cases where regional anesthesia was not reliable and the transition to general anesthesia was performed due to the obvious technical difficulties of its implementation, while obtaining various complications directly during surgery (Moore, 2019). At the same time, patients themselves often consciously choose general anesthesia. For this reason, the use of combined anesthesia is justified, which combines the main advantages of regional anesthesia and minimizes the disadvantages of general anesthesia.

In the past few decades, in the practice of clinical anesthesiology, there has been a significant increase in the interest in changing the state of the centers of higher nervous activity after the introduction of general anesthesia. This circumstance leads to the emergence of the concept of postoperative cognitive dysfunction in modern medical terminology, while the terms moderate cognitive impairment and pre-dementia state were widely used in the relevant medical literature as an independent position. In this context, the patients with atherosclerotic lesions of the brachiocephalic vessels who are indicated for carotid endarterectomy are of considerable interest (Galyfos et al, 2019). The complexity of such situations lies in the fact that the majority of patients with critical stenosis of the internal carotid artery have disorders of higher mental functions due to chronic cerebral ischemia, which can bring about a significant negative development due to intraoperative clamping

of the common carotid artery and damaging effect of drugs for general anesthesia. Similar questions have been raised in a series of clinical studies. However, they do not contain the qualitative assessment of combined influence of factors of surgical aggression and general anesthesia.

It is generally accepted that the study of saturation of brain tissues during carotid endarterectomy can rightfully be associated with a decrease in the likelihood of clinical manifestations of coronary brain disease, occurrence of a stroke, as well as decrease in the total time spent in the intensive care unit of a medical institution. At the same time, patients with the initial stage of vascular dementia (this mainly applies to elderly patients) can improve their mental activity through carotid endarterectomy, and can slow down the progression of cognitive dysfunction as a result of stable restoration of blood supply to the brain. Possible complications caused by both the surgery itself and consequences of anesthesia should not be discounted (Oikawa et al, 2017).

Numerous scientific studies performed in clinical settings over the past few decades clearly indicate that carotid endarterectomy in combination with therapy using medications significantly reduces the risk of stroke and enhances long-term survival after the operation. In patients with a decrease in the carotid artery of 70–99 %, 50–69 %, or 60–99 %, the probability of developing a stroke or death in the period of five to six years after CEE decreases by 16 %, 8 %, or 5 %, respectively. However, CEE may only be recommended in situations where the requirements outlined by the Carotid Endarterectomy Committee of the American Heart Association are met. They contain clear distinctions, according to which the incidence of homolateral strokes after surgical interventions should not exceed 3 % in asymptomatic patients, 5 % in patients with TIA, and 7 % in patients undergoing the stage of recovery after a stroke. The cumulative frequency of deaths in any of these groups should not exceed 2 %. In modern conditions, CEE should be considered the gold standard for the treatment of stenosing injuries of the internal carotid arteries. At the same time, in regular medical practice, the majority of patients have simultaneous damage to several arterial basins, which in certain situations worsens their prognosis and gives reason to doubt the need for surgery, since its risk can significantly exceed the possible benefit.

Drug correction of real cognitive disorders, in particular of those occurring during local anesthesia, is of strong interest in the medical community. In this context, the issues of using special techniques for correcting the processes of gas exchange and brain metabolism during carotid revascularization are of fundamental importance from the point of view of the prospects for the treatment and prevention of the onset of cognitive disorders, as well as in search for new opportunities to eliminate problems with cerebral circulation in patients of different ages suffering from carotid stenosis (Megaly et al, 2021). Two off the main pathogenetic mechanisms of the formation and subsequent development of ischemia should be noted, namely hemodynamic mechanism which is directly associated with impaired cerebral perfusion due to stenosis of the extra- and intracranial arteries and increase in the size of the atherosclerotic plaque, and embolic mechanism initiated by occlusion of the intracranial arteries by an embolic substrate in form of thrombotic masses that form on the surface of an atherosclerotic plaque, as well as by fragments of the plaque itself due to the violation of the integrity of its surface. Stenosis of the internal carotid arteries is largely due to the high risk of developing both hemodynamic and embolic factors for stroke. In this context, carotid endarterectomy in combination with percutaneous transluminal angioplasty with stenting should be considered the main surgical techniques for the prevention of acute cerebrovascular events in the carotid systems (Fassaert et al, 2019).

It is well known that when determining the probability of developing an ischemic stroke to clarify indications for angiosurgery in combination with an assessment of clinical symptoms, the main attention should be paid to the general state of cerebral hemodynamics, degree of stenosis, characteristics of the atherosclerotic plaque, cerebrovascular reserve, and general state of collateral circulation. A wide variety of available imaging methods allows us to directly or indirectly form an assessment of the real state of cerebral blood flow. These methods are based on practical experience in tracking various physiological mechanisms, which allow us to make an assumption about the presence of cerebral hemodynamic disorders in each specific case under study (Besli et al, 2019).

Significant achievements in vascular surgery over the past few years, accomplished directly in the treatment of ischemic brain lesions, have taken place due to the use of microvascular and endovascular techniques, which is a clear evidence that the methods used have significant advantages over conservative methods of treatment. At the same time, the real percentage of ischemic complications and deaths during reconstructive operations on the main cerebral arteries is still very high (Choy et al, 2018). The risk of surgical operations as a combination of possible complications and deaths in various clinics of vascular surgery ranges from 4.5 to 14 %. Simultaneous lesions of both carotid basins cause a boundary tension of the existing mechanisms of collateral compensation, and also become one of the main causes of cerebral ischemia. The correct choice of surgical intervention in patients with lesions of both carotid arteries is quite difficult, especially in cases where there is a combination of carotid artery occlusion with stenosis of the contralateral internal carotid artery, provided that the stenosis reconstruction is unsafe due to a high risk of ischemic disorders. According to various statistical estimates, the mortality in this group of patients reached 15 %, while 16 % had various clinical abnormalities. In such conditions, a correct assessment of the degree of cerebral hemodynamic disorders is an important aspect in terms of achieving high treatment efficiency in general.

Conclusions

The performed scientific study of the features of gas exchange and brain metabolism during revascularization of the carotid arteries led to the following conclusions. When performing carotid endarterectomy, as well as carotid stenting, the frequency and nature of cerebrovascular complications such as stroke, transient ischemic attack, as well as cardiovascular complications represented by acute coronary syndrome, myocardial infarction in

various postoperative periods (immediate and long-term) do not differ significantly (p0.05). For carotid endarterectomy, the main risk factors for cerebrovascular complications, contralateral occlusion should be considered in patients who had a stroke less than six months ago (p0.05), while the age over 75 years should also be taken into account in patients in need of a temporary intraluminal shunt (p0.05). Hypoechoic heterogeneous type of atherosclerotic plaque (p0.05), as well as ulceration of the surface of atherosclerotic plaque (p0.05) should be considered as key risk factors for cerebrovascular complications for carotid stenting.

The key risk factor for the development of cardiovascular complications for carotid endarterectomy should be considered, such as the presence of initial *angina pectoris* of stage III, related to the functional class (p0.05). No cardiovascular risk factors were found for carotid stenting. Both, carotid endarterectomy and carotid stenting, should be considered effective methods for the prevention and treatment of cerebral circulatory disorders in patients with carotid artery stenosis, and the results of treatment carried out for three years do not show significant mutual differences (p0.05). The conditions for carotid endarterectomy is considered best in patients who have passed the six-month late recovery period after the stroke and have the diagnosis of carotid artery occlusion, in patients not over 75 years of age and in need of a temporary internal shunt, while in patients suffering from cardiac pathology the initial exertional angina should not exceed functional class II. The optimal conditions for carotid stenting can be assumed to be the fact that a patient has an is echogenic, homogeneous, or heterogeneous hyperechoic atherosclerotic plaque without surface ulceration.

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