

PREDICTORS OF THE DYNAMICS OF CHANGES IN COGNITIVE FUNCTIONS IN PATIENTS 6 MONTHS AFTER CAROTID ENDARTERECTOMY

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ABSTRACT

Background. Carotid atherosclerosis is one of the urgent problems due to the high risk of developing ischemic stroke and cognitive impairment. The dynamics of clinical disorders in patients with carotid stenosis is determined by a complex of neuro-physiological, angiological, tissue and biomolecular reactions, the characteristics of which can act as predictors of the course of the pathology.

The aim of the work. To determine the neurophysiological parameters and predictors of cognitive dysfunction in patients who underwent carotid endarterectomy.

Materials and methods. The study included 59 people with carotid atherosclerotic disease. All included patients underwent carotid endarterectomy. We assessed the degree of stenosis of the internal carotid artery and cognitive status using the FAB (Frontal Assessment Battery) scale and MoCA (Montreal Cognitive Assessment) Test and recorded electroencephalogram (EEG), P300 cognitive evoked potentials and heart rate variability in patients at various terms (before surgery, 6 months after the surgery). Patients were divided into groups based on the dynamics of cognitive tests using cluster analysis (k-means) with identification of elements included in the clusters: patients of cluster 1 had a "preserved" profile of cognitive status; patients of cluster 2 – moderate cognitive dysfunction.

Results. Patients of cluster 1 had a higher power of beta oscillations in the frontal lead, a higher amplitude of the P3 component of the P300 potential, and a greater variability of R-R intervals in terms of the total indicator and high-frequency power. We proposed a model that allows us to classify patients into groups according to the dynamics of cognitive function scores. According to the data obtained, the most significant predictors of the dynamics of cognitive status were the initial characteristics of the EEG and the P300 cognitive evoked potential.

Conclusions. We determined the clinical and neurophysiological correlates of cognitive dysfunction: an association with greater preservation of activating effects on the EEG, processes of recognition and decision-making in the associative zones of the cortex, and less pronounced activity of stress-implementing mechanisms. Indicators of EEG spectral analysis and characteristics of the P300 cognitive evoked potential are predictors of the cognitive status dynamics.

Key words: carotid atherosclerosis, P300 cognitive potential, carotid endarterectomy, cognitive functions, artificial neural networks, cluster analysis

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ПРЕДИКТОРЫ ДИНАМИКИ ИЗМЕНЕНИЯ КОГНИТИВНЫХ ФУНКЦИЙ У ПАЦИЕНТОВ ЧЕРЕЗ 6 МЕСЯЦЕВ ПОСЛЕ КАРОТИДНОЙ ЭНДАРТЕРАКТОМИИ

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РЕЗЮМЕ

Актуальность. Атеросклеротическое поражение сонных артерий является одной из актуальных проблем в связи с высоким риском развития ишемического инсульта и когнитивных нарушений. Динамика клинических нарушений у пациентов с каротидными стенозами определяется комплексом нейрофизиологических, ангиологических, тканевых и молекулярно-биологических реакций, характеристики которых могут выступать в роли предикторов течения патологии.

Цель работы. Определение нейрофизиологических параметров и предикторов когнитивной дисфункции у пациентов, перенёсших каротидную эндартерэктомию.

Материалы и методы. В исследование было включено 59 человек с атеросклеротическим поражением сонных артерий. Все включённые пациенты подвергались каротидной эндартерэктомии. У пациентов в различные сроки (до операции, через 6 месяцев после вмешательства) производилась оценка степени стеноза внутренней сонной артерии, регистрация электроэнцефалограммы (ЭЭГ), когнитивных вызванных потенциалов P300, вариабельности сердечного ритма, а также оценка когнитивного статуса по шкалам FAB (Frontal Assessment Battery), MoCA (Montreal Cognitive Assessment) Test. Пациенты были разделены на группы на основе динамики когнитивных тестов методом кластерного анализа (k-средних) с идентификацией элементов, входящих в кластеры: кластер 1 – с «сохранным» профилем когнитивного статуса; кластер 2 – с умеренными когнитивными нарушениями.

Результаты. В кластере 1 определяется более высокая мощность бета-колебаний в лобных отведениях, амплитуда компонента P3 потенциала P300, а также большая вариабельность R-R интервалов по суммарному показателю и высокочастотной мощности. Нами была предложена модель, позволяющая классифицировать пациентов в группы по динамике балльной оценки когнитивных функций. Согласно полученным данным, наиболее значимыми предикторами динамики когнитивного статуса являлись исходные характеристики ЭЭГ и когнитивного вызванного потенциала P300.

Выводы. Выявлены клиничко-нейрофизиологические корреляты когнитивной дисфункции: ассоциация с большей сохранностью активизирующих влияний на ЭЭГ, процессов опознания и принятия решения в ассоциативных зонах коры, меньшей выраженностью активности стресс-реализующих механизмов. Показатели спектрального анализа ЭЭГ и характеристики когнитивного вызванного потенциала P300 являются предикторами динамики когнитивного статуса.

Ключевые слова: атеросклероз сонных артерий, когнитивный потенциал P300, каротидная эндартерэктомия, когнитивные функции, искусственные нейронные сети, кластерный анализ

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INTRODUCTION

Carotid atherosclerosis is one of the urgent problems of both neurology and vascular surgery due to the high risk of developing ischemic stroke and cognitive impairment in asymptomatic patients [1–3].

The dynamics of clinical disorders in patients with carotid stenosis is determined by a complex of neurophysiological, angiological, tissue and biomolecular pathological and compensatory-adaptive reactions, the characteristics of which can act as predictors of the course of cerebrovascular pathology [4–6].

An important clinical characteristic of patients with hemodynamically significant stenosis of the carotid arteries is cognitive impairment [7, 8] associated with brain perfusion limitations and secondary changes in the trophism of the associative cortical zones [9, 10].

One of the objective correlates of cognitive impairments are endogenous evoked potentials (potentials associated with events) – P300, reflecting the psychophysiological processes of stimulus recognition and decision-making in relation to it [11]. There are also data on the relationship between neurodynamic cognitive impairments and the activity of ergotropic and trophotropic mechanisms of autonomic support of behavior [12]. Ultrasound and clinical laboratory characteristics in this group of patients can equally be considered as variables influencing cognitive status [13, 14].

In this regard, a relevant issue is the study of the role of these indicators as correlates of the cognitive status dynamics in patients with carotid stenosis.

THE AIM OF THE STUDY

To determine the neurophysiological parameters and predictors of cognitive dysfunction in patients who underwent carotid endarterectomy.

MATERIALS AND METHODS

The study included 59 patients between 2021 and 2022. Patients included in the study were grouped as “symptomatic” (group 1; $n = 33$), with acute cerebrovascular accidents in a medical history, and as “asymptomatic” (group 2; $n = 26$), without acute cerebrovascular accidents in a medical history, according to brain magnetic resonance imaging. All included patients underwent carotid endarterectomy according to clinical guidelines [15]. The surgical technique (classical or eversion) was selected based on the preferences of the operating surgeon, the atherosclerotic plaque extent on the internal and common carotid arteries, and the carotid bifurcation level. A Dacron patch was used for the classical technique. The groups were comparable in terms of the surgery type. All surgical interventions were performed using total combined anesthesia. Artificial lung ventilation was performed using a Dräger Primus breathing apparatus (Dräger, Germany) in the IPPV mode under normoventilation conditions ($\text{PaCO}_2 = 35\text{--}45$ mm Hg) with ventilation parameter control. General data on the patients are presented in Table 1; both groups of patients were comparable in age and the presence of concomitant pathology, as well as in the intervention technique.

TABLE 1

GENERAL CHARACTERISTICS OF THE PATIENTS

Indicators	Group 1 ($n = 33$)	Group 2 ($n = 26$)	p^*
Age (years)	66.7 ± 8.2	68.2 ± 7.1	–
Gender	male – 21 (63.6 %) female – 12 (36.4 %)	male – 17 (65.3 %) female – 9 (34.7 %)	–
Side of the ICA lesion	left – 19 right – 14	left – 17 right – 9	0.288 0.234
Hypertension	30 (90.9 %)	23 (88.4 %)	0.424
Ischemic heart disease	10 (30.3 %)	12 (46.1 %)	0.123
Postinfarction cardiosclerosis	3 (9 %)	4 (15.3 %)	0.302
Type 2 diabetes mellitus	8 (24.2 %)	4 (15.3 %)	0.155
CEA procedure technique	classical – 15 (45.4%) eversion – 18 (54.6%)	classical – 12 (46.1%) eversion – 14 (53.9%)	0.519 0.457
Temporary intraluminal shunting	7 (21.2 %)	5 (19.2 %)	0.378
Intraoperative ICA clamping time (s)	1567 [1390; 1780]	1597 [1335; 1723]	0.759

Note. ICA – internal carotid artery; CEA – carotid endarterectomy.

The inclusion criteria were the presence in patients of: internal carotid artery stenosis according to expert ultrasound examination of the brachiocephalic arteries (US-BCA) of 70–99 % according to NASCET (North American Symptomatic Carotid Endarterectomy Trial) in the absence of transient ischemic attack (TIA) episodes or acute cerebrovascular accident (CVA); internal carotid artery stenosis according to expert BCA ultrasound from 50 to 60 % according to NASCET, considering morphological instability of the atherosclerotic plaque (ulceration, hemorrhage into the plaque, intimal flotation, mural thrombus) and neurological symptoms – TIA or stroke; internal carotid artery stenosis according to expert BCA ultrasound of more than 60 % according to NASCET in the presence of episodes of TIA or CVA [16]. Patients with contralateral internal carotid stenosis were not included in the study. Exclusion criteria were: contralateral internal carotid artery stenosis; hearing impairment that prevents testing; patient refusal to participate in the study; systemic disease (renal, liver, gastrointestinal, hematological, immunological disease, etc.); degenerative diseases of the nervous system (Alzheimer's disease, Huntington's chorea, Parkinson's disease, amyotrophic lateral sclerosis, frontotemporal degeneration).

Exclusion criteria during the observation period were: death; any cardiovascular events; refusal to continue the study.

Patients received standard antiplatelet (monotherapy with aspirin 100 mg or in combination with clopidogrel 75 mg) and lipid-lowering (3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibitors in a dose according to the level of low-density lipoproteins) therapy, and did not take drugs that affect cognitive functions (central acetylcholinesterase inhibitors or acatinol memantine, etc.).

In patients, the degree of internal carotid artery stenosis was assessed using ultrasound data at different times (before surgery (1–5 days before the intervention) – visit 1; 6 months after the intervention – visit 2); in some cases, computed tomography with angiography and/or digital subtraction angiography were used as a confirmation method. Electroencephalogram (EEG), cognitive evoked potentials (P300), heart rate variability (HRV) were recorded, and cognitive status was assessed using the Frontal Assessment Battery (FAB) and the Montreal Cognitive Assessment (MoCA Test).

Ultrasound examination was performed on a GE Vivid S5 device (GE HealthCare, USA) with a linear sensor with a frequency of 12 MHz; magnetic resonance imaging was performed on a MAGNETOM Symphony 1.5 Tesla device (Siemens, Germany).

EEG was recorded using a 19-channel digital electroencephalograph Neurospectr-3 and the corresponding Neuron-spectr software (Neurosoft LLC, Russia) [17]. The electrodes were mounted according to the 10–20 % scheme (Fp1, Fp2, F7, F3, F4, F8, T3, C3, C4, T4, T5, P3, P4, T6, O1, O2, Fz, Cz, Pz) with reference electrodes on the ears A1 and A2. The quantization frequency of the analog-to-digital converter was 200 Hz, the high-pass filter (time constant) was 0.5 Hz (0.32 s), and the low-pass filter was 75 Hz.

The average analysis epoch was 20.48 s (4096 samples). EEG was recorded in the background state. Before conducting the EEG mathematical analysis, artifacts were identified and excluded from the analysis, as well as epileptiform activity was identified both visually and by software detection of spikes and sharp waves. Recording fragments without artifacts were used for the analysis. The EEG analysis was performed using spectral analysis methods based on the fast Fourier transform with the allocation of the following frequency ranges: delta (0.5–3.9 Hz), theta (4.0–7.9 Hz), alpha (8–13 Hz), beta-1 (14–19.9 Hz), beta-2 (20–35 Hz), gamma (36–100 Hz). The following parameters were studied during the spectral analysis: total power; average power; average amplitude and average frequency of alpha oscillations, beta1 and beta2 oscillations, theta and delta oscillations. Cognitive evoked potential P300 registration was performed to assess the activity of the sensory systems. The auditory evoked potentials (EP) study was carried out by recording long-latency auditory EPs, reflecting to a greater extent the function of the auditory analyzer thalamocortical section. For stimulation using headphones, binaurally, clicks with a duration of 50 ms, a filling of 1000 Hz, a frequency of 1–1.5 Hz with a random component (to exclude the phenomenon of habituation to periodicity) were used; the gain was 5–20 $\mu\text{V}/\text{mm}$, the analysis epoch was 500 ms, the number of summations (averaging) was 100. The cognitive evoked potential P300 was recorded in the odd-ball paradigm during the presentation of sound stimuli and the patient's active response to a significant (deviant) stimulus (button pressing) using the "Neuron-Spectrum.DVP" hardware and software complex (Neurosoft LLC, Russia) [17]. Electrocardiogram (ECG) was recorded using the "VNS-Micro" device and the "Poli-Spectrum.NET" program (Neurosoft LLC, Russia). The vegetative regulation mechanisms were assessed by recording and analyzing heart rate variability using the "Poli-Spectrum.NET" hardware and software complex (Neurosoft LLC, Russia) [18]. The assessment was performed in a sitting position in the 1st standard ECG lead; then statistical and spectral analyses of the dynamic series of R-R intervals were performed.

Statistical data processing was performed using the Statistica 10.0 software package (StatSoft Inc., USA). Descriptive statistics included the median (Me), lower and upper quartiles (LQ; UQ). Quantitative data comparison was performed using the Mann – Whitney statistical criterion (U; the normalized indicator is Z); for qualitative data, 2 × 2 conjugation tables and the chi-square criterion were used. Differences were considered statistically significant at $p < 0.05$. To isolate subgroups of patients, the cluster analysis method (k-means) was used with identification of elements included in the clusters. The problem of classifying patients into groups with known clinical characteristics was solved based on machine learning technology (artificial neural networks) using the studied neurophysiological parameters as input parameters. The artificial neural network performance was assessed on the training, control, and test samples. The software package Statistica 10.0 (StatSoft Inc., USA) was used.

All patients signed informed consent; the study was approved by the local Ethics Committee of the Ryazan State Medical University named after Academician I.P. Pavlov of the Ministry of Health of the Russian Federation (protocol No. 3 dated October 11, 2021).

RESULTS OF THE STUDY

To solve the problem of identifying factors that predict the trajectory of patients' cognitive functioning, we implemented a formalized procedure for categorizing patients into homogeneous groups based on the dynamics of cognitive tests using the cluster analysis method (clustering by the k-means method).

Table 2 shows the results of cluster analysis based on changes in FAB and MoCA Test indicators at visit 1 (before surgery) and 6 months after surgery.

As follows from Table 2, cluster 1 is characterized by a more preserved cognitive status compared to cluster 2 according to the selected indicators, in connection with which cluster 1 is designated as a group with a preserved profile of cognitive status, cluster

2 – as a group with moderate cognitive impairment (according to the MoCA Test indicator).

A fundamentally important fact is the absence of statistically significant differences in the presence of the previous ischemic stroke factor in the anamnesis in the groups (in cluster 1: 55 % with a history of stroke, 45 % without a history of stroke; in cluster 2 – 52 % and 48 %, respectively; $\chi^2 = 0.06$; $p = 0.83$).

Table 3 presents the neurophysiological indicators in the clusters.

A statistically significantly higher power of beta oscillations in the frontal leads in cluster 1 is determined; as well as higher amplitude of the P300 potential P3 component in this cluster. When studying the heart rate variability in cluster 1, a greater variability of the R-R intervals by the total indicator and high-frequency power are revealed.

Table 4 presents the correlations between neurophysiological indicators and the scoring level of cognitive functions in clusters.

As follows from the table, statistically significant correlations are determined between the P300 potential amplitude and the cognitive function score level at visit 1 (for groups 1 and 2) and at visit 2 (after 6 months).

TABLE 2

DYNAMICS OF INDICES OF COGNITIVE FUNCTIONS

Indicators	Cluster 1 (n = 33)	Cluster 2 (n = 26)	Statistical indicators	
	Me (LQ; UQ)	Me (LQ; UQ)	U (Z)	p
FAB, visit 1	17 (17; 18)	16 (14; 16)	70 (3.6)	0.001
FAB, visit 2	18 (17; 18)	16 (16; 17)	62 (3.8)	0.001
MoCA Test, visit 1	26 (25; 28)	23 (22; 24)	43 (4.3)	0.001
MoCA test, visit 2	27 (26; 29)	25 (24; 26)	33 (4.6)	0.001

TABLE 3

NEUROPHYSIOLOGICAL PARAMETERS IN SELECTED CLUSTERS

Indicators	Cluster 1	Cluster 2	Statistical indicators	
	Me (LQ; UQ)	Me (LQ; UQ)	U (Z)	p
Power of EEG beta oscillations in lead F3, $\mu V \times ms$	5 (4; 6)	4 (3; 5)	48 (2.01)	0.048
Amplitude of potential P300 in lead P3 after surgery, μV	6.9 (2.9; 7.4)	2.8 (0.9; 6.4)	14.5 (2.25)	0.024
Amplitude of potential P300 in lead Cz after surgery, μV	6.4 (5.8; 8.0)	2.4 (0.8; 5.4)	9 (2.73)	0.007
RMS HRV, ms	29 (16; 44)	17 (10; 25)	45 (2.12)	0.034
HF HRV, ms	177 (36; 328)	26 (17; 120)	48 (1.9)	0.047

Note. RMS HRV – variability of R-R intervals according to the total indicator, HF HRV – high-frequency power.

We proposed a model based on artificial neural network (ANN) technology, which allows classifying patients into groups based on the cognitive function score dynamics based on the above-described neurophysiological indicators. The model with optimal characteristics was a multilayer perceptron with 29 input neurons, 7 intermediate layer neurons, and 2 output neurons (MLP 29-7-2). The model demonstrated 100 % training performance, 78 % test sample performance (BFGS 7 training algorithm).

In the test sample, a smaller number of correct solutions were found in cluster 2 (70 % correct answers; in cluster 1 – 100 %); that is, the more difficult task was to classify subjects into cluster 2. The area under the ROC-curve was 0.950 (good quality of the model) (fig. 1).

Table 5 presents the ranked (in order of decreasing importance) neurophysiological indicators used to solve the classification problem.

As follows from Table 5, the most significant predictors of the cognitive status dynamics in patients who underwent carotid endarterectomy were the EEG characteristics and the cognitive evoked potential P300 characteristics.

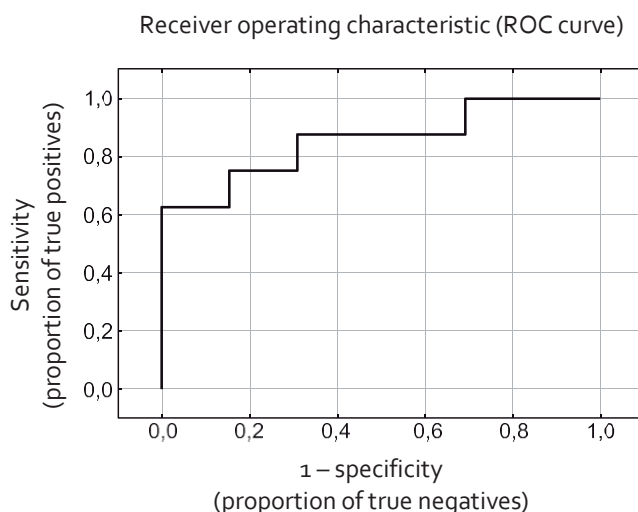


FIG. 1. ROC-curve of the classification model into the studied clusters

TABLE 4

CORRELATIONS OF NEUROPHYSIOLOGICAL INDICES IN CLUSTERS

Groups of indicators	Cluster 1		Cluster 2	
	correlation	p	correlation	p
FAB (visit 1), P200 CEP amplitude in lead Fz	0.494	0.044	–	–
MoCA Test (visit 1), P300 CEP amplitude in lead Cz	–	–	0.632	0.029
MoCA Test (visit 2), P300 CEP amplitude in lead Cz	–	–	0.539	0.039

Note. CEP – cognitive evoked potential.

TABLE 5

NEUROPHYSIOLOGICAL INDICATORS USED FOR CLASSIFICATION AND RANKED IN THE DESCENDING ORDER OF SIGNIFICANCE

Groups of indicators	Characteristics	
	Rank*	Sensitivity
EEG alpha oscillation power in lead O1, $\mu\text{V} \times \text{ms}$	1	3.0
HF HRV	2	2.5
P2N2 P300 amplitude in lead Fz	3	2.5
P3 P300 latency in lead Fz	4	2.0
EEG beta oscillation frequency in lead F3	5	2.0
EEG alpha oscillation power in lead O2, $\mu\text{V} \times \text{ms}$	6	2.0
EEG theta oscillation frequency in lead F3, counts/s	7	2,0

Note. * – the first 7 indicators with the highest level of sensitivity are presented; HF HRV – high-frequency power.

DISCUSSION

The absence of statistically significant neurophysiological differences in the previous stroke factor in patients with carotid stenosis indicates the need to search for other predictors of the cognitive status dynamics, which is consistent with the literature data [19, 20]. This report presents mainly neurophysiological correlates and predictors of the dynamics of cognitive functions; at the same time, the role of factors associated with clinical status [19], biomolecular and neurotransmitter mechanisms [21, 22] is undoubted.

It was revealed that the preserved cognitive status (cluster 1) is associated with indirect signs of greater brain activation (according to beta1 EEG oscillations), a greater cognitive evoked potential P300 amplitude, as well as with a lesser expression of sympathetic influences (less activity of stress-realizing systems). At the same time, statistically significant correlates of a higher score for cognitive functions of the first visit and the visit after surgery were indicators reflecting the preservation of the stimulus recognition and decision-making mechanisms in relation to it, which also corresponds to literature data [11].

Machine learning technologies are widely used to solve problems in both clinical neurology and clinical angiology [23]. The use of neurophysiological indicators as predictors allowed us to create a model for classifying subjects into groups based on ANN technology. The model was more sensitive to identifying a group with less pronounced cognitive impairment. The most significant predictors of the cognitive status dynamics were the characteristics of the EEG spectral analysis and the cognitive evoked potential P300 indicators.

CONCLUSIONS

In patients with atherosclerotic lesions of the carotid arteries who underwent carotid endarterectomy, the presence of clinical and neurophysiological correlates was revealed: an association of preserved cognitive functions with a more pronounced activation of cortical structures, activity of cortex associative zones, and a lesser expression of the activity of stress-realizing mechanisms. The EEG spectral analysis indicators and the cognitive evoked potential P300 characteristics during recognition and decision-making in relation to a sensory stimulus can be used as additional predictors of the cognitive status dynamics in patients with carotid stenosis using machine learning technologies. At the same time, the stroke factor does not have a statistically significant effect on the cognitive status of patients.

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Conflicts of interest

No potential conflict of interest relevant to this article reported.

REFERENCES

1. Chang RW, Tucker LY, Rothenberg KA, Lancaster E, Faruqi RM, Kuang HC, et al. Incidence of ischemic stroke in patients with asymptomatic severe carotid stenosis without surgical intervention. *JAMA*. 2022; 327(20): 1974-1982. doi: 10.1001/jama.2022.4835
2. Kaveshnikov VS, Serebryakova VN, Trubacheva IA, Shalnova SA. Carotid atherosclerosis severity in unorganized adult population. *Rational Pharmacotherapy in Cardiology*. 2019; 15(1): 84-89. (In Russ.). [Кавешников В.С., Серебрякова В.Н., Трубачева И.А., Шальнова С.А. Выраженность каротидного атеросклероза у взрослого неорганизованного населения. *Рациональная фармакотерапия в кардиологии*. 2019; 15(1): 84-89]. doi: 10.20996/1819-6446-2019-15-1-84-89
3. Kazantsev AN, Chernykh KP, Zarkua NE, Abdullaev AD, Povtoreiko AV, Bagdavadze GS, et al. Eversion carotid endarterectomy with transposition of the internal carotid artery according to A.N. Kazantsev. Hospital and long-term results. I.P. Pavlov *Russian Medical Biological Herald*. 2021; 29(1): 73-88. (In Russ.). [Казанцев А.Н., Черных К.П., Заркуа Н.Э., Абдуллаев А.Д., Повторейко А.В., Багдавадзе Г.Ш., и др. Эверсионная каротидная эндартерэктомия с транспозицией внутренней сонной артерии по А.Н. Казанцеву. Госпитальные и отдаленные результаты. *Российский медико-биологический вестник им. академика И.П. Павлова*. 2021; 29(1): 73-88]. doi: 10.23888/PAVLOVJ202129173-88
4. Pyshkina LI, Abieva AR, Iasamanova AN, Darvish NA, Kamchatnov PR, Kabanov AA, et al. Dynamic of cerebrovascular disorders in patients with carotid stenosis. *S.S. Korsakov Journal of Neurology and Psychiatry*. 2018; 118(9-2): 8-13. (In Russ.). [Пышкина Л.И., Абиева А.Р., Ясаманова А.Н., Дарвиш Н.А., Камчатнов П.Р., Кабанов А.А., и др. Течение цереброваскулярной патологии у больных со стенозирующим поражением сонных артерий. *Журнал неврологии и психиатрии им. С.С. Корсакова*. 2018; 118: 8-13]. doi: 10.17116/jnevro20181180928
5. Matyushkin AV, Mustafin AKh. Results of carotid endarterectomy in patients after previous stroke. *Pirogov Russian Journal of Surgery*. 2021; (3): 50-56. (In Russ.). [Матюшкин А.В., Мустафин А.Х. Результаты каротидной эндартерэктомии в лечении пациентов, перенесших ишемический инсульт. *Хирургия. Журнал им. Н.И. Пирогова*. 2021; 3: 50-56]. doi: 10.17116/hirurgia202103150
6. Meershoek AJA, de Waard DD, Trappenburg J, Zeebregts CJ, Bulbulia R, Kappelle JLJ, et al.; Delphi consensus experts panel. Clinical response to procedural stroke following carotid endarterectomy: A Delphi Consensus Study. *Eur J Vasc Endovasc Surg*. 2021; 62(3): 350-357. doi: 10.1016/j.ejvs.2021.05.033
7. Khasanova DR, Zhitkova YV, Gasparyan AA. Importance of atherosclerotic stenotic lesion of the brachioce-

- phalic arteries in the development of cognitive impairments. *Neurology, Neuropsychiatry, Psychosomatics*. 2015; 7(1): 43-48. (In Russ.). [Хасанова Д.Р., Житкова Ю.В., Гаспарян А.А. Значение атеросклеротического стенозирующего поражения брахиофациальных артерий в формировании когнитивных нарушений. *Неврология, нейропсихиатрия, психосоматика*. 2015; 7(1): 43-48]. doi: 10.14412/2074-2711-2015-1-43-48
8. Sridharan ND, Asaadi S, Thirumala PD, Avgerinos ED. A systematic review of cognitive function after carotid endarterectomy in asymptomatic patients. *J Vasc Surg*. 2022; 75(6): 2074-2085. doi: 10.1016/j.jvs.2021.12.059
9. Ge Y, Li Q, Nie Y, Gao J, Luo K, Fang X, et al. Dexmedetomidine improves cognition after carotid endarterectomy by inhibiting cerebral inflammation and enhancing brain-derived neurotrophic factor expression. *J Int Med Res*. 2019; 47(6): 2471-2482. doi: 10.1177/0300060519843738
10. Ivanova LG, Mkrtchyan VR, Khaikin VD, Gudkova AA, Kudukhova KI, Druzhkova TA. The role of brain-derived neurotrophic factor (BDNF) in the development of vascular cognitive impairment. *Bulletin of Neurology, Psychiatry and Neurosurgery*. 2020; 12: 67-78. (In Russ.). [Иванова Л.Г., Мкртчян В.Р., Хайкин В.Д., Гудкова А.А. Кудухова К.И., Дружкова Т.А. Роль нейротрофического фактора мозга (BDNF) в развитии когнитивных нарушений сосудистой генеза. *Вестник неврологии, психиатрии и нейрохирургии*. 2020; 12: 67-78]. doi: 10.33920/med-01-2012-07
11. Nahas NE, Zaki A, Zakaria M, Naser AAE, Bassiony AE, Abdeldayem E, et al. Cognitive impairment in asymptomatic cerebral arterial stenosis: A P300 study. *Neurol Sci*. 2023; 44(2): 601-609. doi: 10.1007/s10072-022-06442-9
12. Sridharan ND, Asaadi S, Thirumala PD, Avgerinos ED. A systematic review of cognitive function after carotid endarterectomy in asymptomatic patients. *J Vasc Surg*. 2022; 75(6): 2074-2085. doi: 10.1016/j.jvs.2021.12.059
13. Whooley JL, David BC, Woo HH, Hoh BL, Raftery KB, Hussain Siddiqui A, et al. Carotid Revascularization and its effect on cognitive function: A prospective non-randomized multicenter clinical study. *J Stroke Cerebrovasc Dis*. 2020; 29(5): 104702. doi: 10.1016/j.jstrokecerebrovasdis.2020.104702
14. Nakamizo A, Amano T, Matsuo S, Kuwashiro T, Yasaka M, Okada Y. Common carotid flow velocity is associated with cognitive function after carotid endarterectomy. *J Clin Neurosci*. 2020; 76: 53-57. doi: 10.1016/j.jocn.2020.04.050
15. Abugov SA, Alekyan BG, Arakelyan VS, Belov YuV, Beloyartsev DF, Vachev AN, et al. *Blockage and stenosis of the carotid artery: Clinical recommendations*. Moscow: Ministry of Health of the Russian Federation; 2016. (In Russ.). [Абугов С.А., Алекян Б.Г., Аракелян В.С., Белов Ю.В., Белоярцев Д.Ф., Вачев А.Н., и др. Закупорка и стеноз сонной артерии: клинические рекомендации. М.: Министерство здравоохранения Российской Федерации; 2016].
16. Ferguson GG, Eliasziw M, Barr HW, Clagett GP, Barnes RW, Wallace MC, et al. The North American Symptomatic Carotid Endarterectomy Trial: Surgical results in 1415 patients. *Stroke*. 1999; 30(9): 1751-1758. doi: 10.1161/01.str.30.9.1751
17. Sysoev Yul, Prikhodko VA, Titovich IA, Karev VE, Okovityy SV. Changes in somatosensory evoked potentials in rats following transient cerebral ischemia. *Acta biomedica scientifica*. 2022; 7(4): 190-200. (In Russ.). [Сысоев Ю.И., Приходько В.А., Титович И.А., Карев В.Е., Оковитый С.В. Изменения соматосенсорных вызванных потенциалов у крыс, перенёсших обратимую церебральную ишемию. *Acta biomedica scientifica*. 2022; 7(4): 190-200]. doi: 10.29413/ABS.2022-7.4.22
18. Mukhametov BG. Review and analysis of ECG decoding software. *Science, Technology and Education*. 2017; 6(36): 70-71. (In Russ.). [Мухаметов Б.Г. Обзор и анализ программного обеспечения для расшифровки ЭКГ. *Наука, техника и образование*. 2017; 6(36): 70-71].
19. Aceto P, Lai C, De Crescenzo F, Crea MA, Di Franco V, Pellicano GR, et al. Cognitive decline after carotid endarterectomy: Systematic review and meta-analysis. *Eur J Anaesthesiol*. 2020; 37(11): 1066-1074. doi: 10.1097/EJA.0000000000001130
20. Babayan GB, Zorin RA, Pshennikov AS, Suchkov IA, Yudin VA, Zhadnov VA, et al. Predictors of neurological deficits in patients with hemodynamically significant stenosis of carotid and vertebral arteries. *Science of the Young (Eruditio Juvenium)*. 2019; 7(4): 533-540. (In Russ.). [Бабаян Г.Б., Зорин Р.А., Пшенников А.С., Сучков И.А., Юдин В.А., Жаднов В.А., и др. Предикторы неврологического дефицита при гемодинамически значимых стенозах сонных и позвоночных артерий. *Наука молодых (Eruditio Juvenium)*. 2019; 7(4): 533-540]. doi: 10.23888/HMJ201974533-540
21. Kalinin RE, Pshennikov AS, Zorin RA, Suchkov IA, Solyanik NA. Biochemical indicators of cerebral damage during operations on the carotid arteries (literature review). *Angiology and Vascular Surgery*. 2022; 28(1): 148-153. (In Russ.). [Калинин Р.Е., Пшенников А.С., Зорин Р.А., Сучков И.А. Соляник Н.А. Биохимические показатели церебрального повреждения при операциях на сонных артериях (обзор литературы). *Ангиология и сосудистая хирургия*. 2022; 28(1): 148-153].
22. Zuniga MC, Tran TB, Baughman BD, Raghuraman G, Hitchner E, Rosen A, et al. A prospective evaluation of systemic biomarkers and cognitive function associated with carotid revascularization. *Ann Surg*. 2016; 264: 659-665. doi: 10.1097/SLA.0000000000001853
23. Qiu J, Tan G, Lin Y, Guan J, Dai Z, Wang F, et al. Automated detection of intracranial artery stenosis and occlusion in magnetic resonance angiography: A preliminary study based on deep learning. *Magn Reson Imaging*. 2022; 94: 105-111. doi: 10.1016/j.mri.2022.09.006

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