ORIGINAL ARTICLE

Neurophysiological Correlates of Neurological Deficiency in Hemodynamically Significant Stenosis of the Arteries of the Neck

ROMAN ALEXANDROVICH ZORIN[1], VLADIMIR ALEKSEEVICH ZHADNOV[2], ROMAN YEVGENYEVICH KALININ[3], ALEXANDER SERGEEVICH PSHENNIKOV[4], NIKITA ANDREEVICH SOLIANIK[5], ALEXANDER OLEGOVICH BURSHINOV[6], GENNADY ALEXANDROVICH LEONOV[7], ANDREW DMITRIEVICH ZAITSEV[8], OLGA VLADIMIROVNA EVDOKIMOVA[9] , MICHAIL MICHAILOVICH LAPKIN[10]

[1]Doctor of Medicine, Associate Professor of Neurology & Neurosurgery, Ryazan State Medical University; ORCID ID 0000-0003-4310-8786;
[2]Doctor of Medicine Head of Department of Neurology and Neurosurgery, Ryazan State Medical University; ORCID ID 0000-0002-5973-1196;
[3]Doctor of Medicine, Head of the Department of Cardiovascular, Roentgen-endovascular, Operative Surgery and Topographic Anatomy, Ryazan State Medical University; ORCID ID 0000-0002-0817-9573;
[4]Doctor of Medicine, Head of General Medicine Faculty, Ryazan State Medical University; ORCID ID 0000-0002-1687-332X;
[5]Postgraduate Student of the Department of Cardiovascular, Roentgen-endovascular, Operative Surgery and Topographic Anatomy, Ryazan State Medical University; ORCID ID 0000-0002-4667-3513;
[6]Doctor of Medicine, Professor of Neurology and Neurosurgery, Ryazan State Medical University; ORCID ID 0000-0002-6951-0290;
[7]Doctor of Medicine, Associate Professor of Neurology & Neurosurgery, Ryazan State Medical University; ORCID ID 0000-0001-5780-1675;
[8]Student of General Medicine Faculty, Ryazan State Medical University; ORCID ID 0000-0002-0987-3436;
[9]PhD, Associate Professor of Neurology and Neurosurgery, Ryazan State Medical University ORCID ID 0000-0002-7075-8410
10 Doctor of Medicine, Head of Department of Physiology and Psychophysiology; Ryazan State Medical University ORCID ID 0000-0003-1826-8307

ABSTRACT

Background: Determination of correlates and predictors of neurological deficit development in hemodynamically significant stenosis of the neck vessels involves not only indicators of systemic and regional blood flow, metabolic characteristics, but also neurophysiological correlates of cognitive functions, autonomic support of activity.
Aim: Identification of the neurophysiological correlates of neurological deficit in hemodynamically significant stenosis of the neck and head vessels for the usage as predictors of this form of pathology.
Methods: 35 patients with hemodynamically significant stenosis of the vessels of the neck and head, identified by ultrasound scanning and Doppler ultrasonography and verified on the basis of selective angiography were investigated. The division of patients into groups was carried out by the method of cluster analysis based on an assessment of the severity of neurological symptoms and the degree of stenosis. The patients underwent spectral analysis and analysis of the coherence function of the electroencephalogram, registration of cognitive evoked potentials P300, and the study of heart rate variability. The selection of significant neurophysiological correlates of neurological deficit in the groups was carried out by the method of artificial neural networks.
Results: Heterogeneity of the group of patients with hemodynamically significant stenosis of the neck vessels in terms of the severity of neurological symptoms was revealed; the neurophysiological indicators that are of the greatest importance in the distribution of patients into groups with different severity of neurological symptoms based on the technology of artificial neural networks have been determined. The characteristics of the cognitive evoked potential were of the greatest importance in solving this problem.
Conclusion: The method of cluster analysis makes it possible to assess the heterogeneity of a group of patients with hemodynamically significant stenosis in terms of the severity of neurological symptoms; at the same time, predictive technologies based on the machine learning methodology help us to distribute patients into groups with different severity of neurological symptoms.
Keywords: hemodynamically significant stenosis of the neck vessels, neurophysiological parameters, cluster analysis, artificial neural networks.

INTRODUCTION

Hemodynamically significant stenosis of the major blood vessels of the neck and head is the main pathogenetic of both chronic cerebral ischemia and ischemic strokes of the hemodynamic type[1].

The main aspect of studying this form of pathology is the study of systemic and regional hemodynamic disorders, including the definition of criteria for selecting patients for surgical treatment[2].

In this regard, it is relevant to determine the correlates and predictors of the development of neurological deficits in hemodynamically significant stenosis of the vessels of the neck of the head, which include not only indicators of blood flow, metabolic features, but also neurophysiological data reflecting dysfunctions of the regulatory structures of the trunk, cognitive impairments, features of autonomic regulation in this group[3].

The objective of the study was to identify neurophysiological correlates of neurological deficit in hemodynamically significant stenosis of the neck and head vessels for their subsequent use as predictors of this form of pathology.

MATERIALS AND METHODS

Thirty five patients with hemodynamically significant stenosis of the neck vessels were examined. The average age of the subjects was 53.5 years; the standard error of the mean is 3.25 years, of which 17 are men and 18 are

women. The primary verification of hemodynamically significant stenosis was based on ultrasound examination of the carotid and vertebral arteries in B-mode, Doppler ultrasound, as well as in duplex scanning mode (GE VIVID S6 apparatus) with estimation of stenosis degree based on NASCET. When hemodynamically significant stenosis was detected, selective carotid angiography with reliable determination of the degree of stenosis was performed. Subsequently, 95% of patients underwent surgery aimed at eliminating hemodynamically significant stenosis.

Registration of the electroencephalogram was performed; the electrodes were positioned according to the "10-20" scheme with reference electrodes on the ears in the background state during the test with the eyes open. Spectral analysis of EEG, study of cross-correlation function in artifact-free areas with determination of power and frequency of theta, alpha, beta1 oscillations was carried out; by calculating inter- and intrahemispheric cross-correlation, as well as the average cross-correlation frequency. Registration was carried out using the Neuron-Spectrum-2 software and hardware complex by Neurosoft (Russia).

The P300 cognitive evoked potential was registered in the oddball paradigm with the presentation of sound stimuli and the patient's active response to a significant (deviant) stimulus (pressing a button). Registration was carried out using the Neuron-Spectrum.LEP software and hardware complex by Neurosoft (Russia).

The assessment of the mechanisms of autonomic regulation was carried out by the method of registration and analysis of heart rate variability using the "Ramena" complex and the "ISCIM 6.0" program (Russia). Registration was performed in a sitting position in the 1st standard ECG lead; further, statistical and spectral analysis of the dynamic series of R-R intervals was carried out.

The division of patients into groups with different severity of neurological symptoms was carried out on the basis of cluster analysis, the NIHSS score, as well as the degree of stenosis of the common or internal carotid artery on the side of the more marked lesion, were assessed as the studied parameters.

Parameters in groups are presented as median (Me), lower (LQ) and upper quartiles (UQ), comparison of parameters in groups was carried out by methods of nonparametric statistics, the Mann-Whitney test (U) was used. When comparing the distribution of patients into groups, 2X2 tables, chi-square test were used.

The problem of classification of patients into groups with known clinical characteristics was solved on the basis of machine learning technology (artificial neural networks) using the studied neurophysiological parameters as input parameters. The performance of an artificial neural network in the training, control, test sample was assessed [4,5].

RESULTS

The studied patients were evaluated before the surgical treatment for hemodynamically significant stenosis (stenting or endarterectomy was performed). On the basis of cluster analysis, 2 groups of patients with hemodynamically significant stenosis were identified; the groups were identified by the K-means method. The first group included 19 people, the second group - 16 people. The characteristics of the groups are presented in Table 1.

Group 1, was characterized by less severity of neurological symptoms and stenosis on the affected side; group 2 was characterized by the opposite characteristics. In group 1, before surgery, 30% had an ischemic stroke (regardless of the side of the lesion), in group 2, 70%. The differences are statistically significant(chi-squared 4.8; p = 0.028).

We assessed the solution to the problem of interrelation of indicators based on the classification of subjects into these groups on the basis of physiological indicators.

We have created a set of artificial neural networks that solve the classification problem - the distribution of subjects into these groups based on the neurophysiological parameters under study.

The optimal characteristics were possessed by the ANN with the following structure: multilayer perceptron, the BFGS learning algorithm; error function entropy, function of activation of hidden neurons - hyperbolic, function of activation of output neurons - softmax. This ANN had 100% performance in the training sample, 80% in the control sample, 90% in the test sample. The results of this ANN are shown in Table 2.

For assessment of significance of indicators for solving the classification problem, the indicators were ranked in descending order of their importance: depending on the sensitivity of the indicators (their influence on solving the classification problem), 3 groups of indicators were identified - 1 group of indicators with a sensitivity of more than 2; 2 group of indicators with sensitivity from 1 to 2; Group 3 - sensitivity less than 1.

In the first group of indicators, the characteristics of the cognitive evoked potential has a prevalence in 40%, the second place was taken by the indicators of the cross-correlation function of the EEG (30%), then the spectral characteristics of the EEG (20%) and HRV (10%).

The indicators of the moderate prognostic significance, in 50% were the characteristics of HRV, 20% were the indicators of P300 and the cross-correlation function of the EEG, and 10% were the characteristics of spectral analysis.

In the 3 group of parameters, the indicators of spectral analysis of EEG, P300, HRV were relatively evenly distributed (near 30% each), 10% were the characteristics of coherence.

In the group of indicators, the indicators of spectral analysis of EEG, P300, HRV (30% each) were relatively evenly distributed, 10% were the characteristics of coherence. Thus, indicators of the cognitive evoked potential P300 are the most significant in solving the problem of classifying subjects into groups.

Table 1: The parameters of neurological status and degree of stenosis in the selected clusters of patients

Parameters	**Group 1**	**Group 2**	**Z**	**p**
	Me; LQ;UQ	**Me; LQ;UQ**		
NIHSS, score	2; 1; 4	10; 9; 11	-3,5	0,001
The degree of stenosis on the affected side, %	65;50;75	73;70;90	-2,0	0,047

Table 2: Percentage of correct decisions in groups based on ANN technology

Samples	Group1	Group 2	All
Training	100%	100%	100%
Control	90%	70%	80%
Test	95%	85%	90%

Table 3: The input parameters of ANN

Indicator rank	Parameter	Sensitivity
1	Latency of P3 component P300 Pz	2834
2	Latency of P3 component P300 Cz	1341
3	Amplitude P2N2 P300 Cz	1300
4	EEG cross-correlation function frequency P_4O_2	1084
5	Alpha rhythm frequency O1	404
6	EEG cross-correlation function frequency O1O2	402
7	Alpha rhythm frequency O2	357
8	Heart rate	48
9	Latency of N_2 component P300 Cz	12
10	EEG cross-correlation function frequency P3O1	9

DISCUSSION

When determining the prognostic factors for the course of hemodynamically significant stenosis of the vessels of the neck and head, it is advisable to identify protective factors and attack factors [6,7].

Neurological disorders in hemodynamically significant stenoses, both transient and persistent focal, are one of the characteristics that determine a decrease in the quality of life, social maladjustment and disability of patients.

In this regard, search for both neurophysiological correlates and, in the future, predictors of the development of neurological disorders is so important, including the choice of tactics for managing patients in this groups [8].

EEG data can reflect both diffuse and regional retardation of the main rhythm, reflected in the spectral and correlation characteristics of the EEG is detected. At the same time, indicators of the cognitive evoked potential, reflecting the neurophysiological correlates of stimulus recognition, decision-making in relation to it, are the most significant, being associated not only with cognitive, but also motor impairments in this group.

The characteristics of autonomic regulation make it possible to reveal the phenomena of sympathicotonia and parasympathicotonia, reflecting autonomic imbalance, leading, through dysregulation of vascular tone, in some cases to the development of transient or persistent disorders of cerebral circulation.

CONCLUSION

The method of cluster analysis makes it possible to assess the heterogeneity of a group of patients with hemodynamically significant stenosis in terms of the severity of neurological symptoms; at the same time, predictive technologies based on the machine learning methodology help us to distribute patients into groups with different severity of neurological symptoms. This allows us to single out the most significant neurophysiological correlates of the insufficiency of neurological functions in this group, which primarily include the indicators of the P300 cognitive evoked potential.

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