Changes in kinesiostabilogram parameters and movement speed of stroke patients while increasing their physical activity due to the use of biofeedback method

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Abstract

Balance disorders are complications of stroke survivors. Aim of this study was the establish effectiveness of the biofeedback approach. In this intervention study 245 patients with early diagnosis of acute disturbance of cerebral circulation (ADCC) were examined. Patients able to move independently were treated by standard conservative ADCC therapy on an outpatient approach, but they continued to have problems with coordination of movement in upright position. Then they were submitted to an increasing physical activity based on five sessions of biofeedback, i.e., a complex rehabilitation of patients with motor pathology "Trust-M" according to TU 9442-001-63704475-2010. Mobility rates were assessed using a web camera. Patients' quality of life was evaluated by SF-36 questionnaire and the Hospital Anxiety and Depression Scale (HADS). All parameters were recorded before and after 5 sessions of biofeedback. After treatment, the stability indicators improved and all patients showed a significant increase in motion rate and quality of life. At the same time, the severity of pain and of depression and anxiety decreased. Negative correlations of average strength between the quadrant and patient HADS scaling rates were obtained. In conclusion, our work shows effectiveness of the biofeedback technique for correcting coordination in stroke survivors.

Key Words: Statokinesiogram; biofeedback; stroke; quality of life; stability; balance; fall.

Eur J Transl Myol 31 (4): 9360, 2021 doi: 10.4081/ejtm.2021.9360

Approximately every sixth elderly inhabitant of the Earth has at least once suffered a stroke or an acute disturbance of cerebral circulation. Along with coronary heart disease, stroke is the main cause of potentially lost years of life and physical health.[1,2] Approximately 90% of patients after a stroke have problems of maintaining equilibrium.[3-5] In addition to injuries, those who fall have limited energy, increased vulnerability and fear of falling.[6,7] They form barriers to social and public activity and adversely affect the quality of life.[8-10] It is difficult to overcome them, as patients require significant cognitive and emotional adaptation to successfully adopt survival strategies.[11-13]

The problem of maintaining equilibrium in movement and/or static vertical position is relevant for people who have suffered a stroke or an acute disturbance of cerebral circulation. Annually, more and more people need rehabilitation procedures after a stroke, including those

due to balance disorders, and the cost of supervising stroke patients who need constant care is high and will be presumably growing in future.[1, 14] To reduce the cost and increase the effectiveness of rehabilitation after a stroke, new methods of rehabilitation are being developed. Seven major risk factors for falling among stroke survivors have been identified in the community, i.e. impaired mobility, decreased balance, use of psychotropic drugs, self-care disability, depression, cognitive impairment, and history of falls.[15,16]
Since locomotion is the result of complex dynamic interactions between the feedback mechanisms and the brain central controller, the best rehabilitation methods require a fundamental understanding of these features of the human gait coordination.[17-19] Therefore, methods using the principle of biological feedback (BFB) are increasingly being used for the rehabilitation of stroke patients. This effect allows to include various sensory data, personal experience, training, particularly motor training, and show that there is a connection between biofeedback and the effectiveness of stroke patients' rehabilitation.[20-22] The purpose of this work was to study the effectiveness of biofeedback in stroke patients' rehabilitation to increase their stability in an upright position.

Materials and Methods

The study was approved by the clinical research ethics committee and was conducted in accordance with the Declaration of Helsinki. All the patients participating in the study gave an informed voluntary written consent. The study was conducted within the period of 2018-2019, in the laboratory of biological feedback (BFB) of Moscow Scientific and Practical Center for Medical Rehabilitation, Restorative and Sports Medicine, Moscow Department of Health (office No. 7). 245 patients with early diagnosed acute disturbance of cerebral circulation (ADCC), or stroke, were examined. Patients were able to move independently, were treated on an outpatient basis; however, all of them had continuous motion coordination problems in an upright position. Patients received standard conservative treatment according to the standard protocol of the Russian Federation. In addition to it, the method of increasing physical activity was used, based on biofeedback - a complex for diagnosing, treatment and rehabilitation of patients with motor pathology "Trust-M" according to TU 9442-001-63704475-2010 (registration certificate for a medical device dated December 16, 2016 Fed No. 2010/08881). In total, 5 sessions of biofeedback were conducted. The study included only those patients who attended all the sessions. The biofeedback sessions were conducted as follows: Patients were in the booth in front of a monitor that shows the booth (top view), the position of the patient and the task (the point where the patient is to move). Accordingly, all the tasks were located at different angles to face the patient, and, performing them, he was forced to move in different directions. In total, the session lasted 720 seconds, during the session the patient receiving 36 tasks. The directional pattern was obtained by smoothing the obtained values. When interpreted: "zero" was the reference point "in the face of the patient", the direction was clockwise. An example of the directional pattern is presented in Figure. 1.

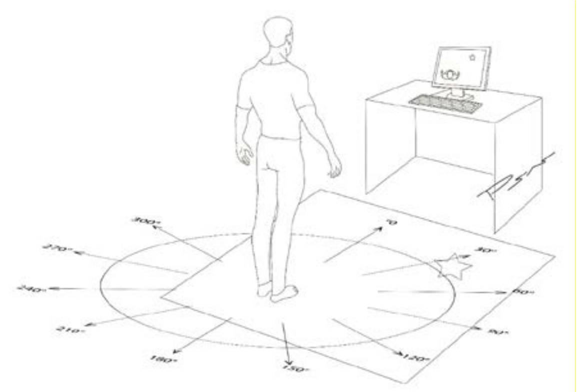

Fig 1. *An example of the directional pattern (side view).*

Stabilometric examination was carried out on the Trust-M equipment according to TU 9442-001-63704475-2010 (registration certificate for a medical device dated December 16, 2016 No. FRS 2010/08881). US research protocol was used, recording time 60 seconds.[23-24] The person assumed a natural standing position with his upper limbs hanging down along the body. The angle of support was natural, the patient's feet parallel. The patient was standing with his eyes open. The subject stopped trying to maintain visual focus at the starting point in front of him, at a distance of 1 meter, at an eye level. The correct measurement was preceded by a 30-second "training" period to stabilize balance, and then the test readings were recorded. During the experiment the researcher was always behind the patient. The patient's movement rates during the biofeedback session were evaluated along 4 quadrants - I (0 º - 89 º), II (90 º - 179 º), III (180 º - 269 º), IV (270 º - 359 º) using a webcam. The patient's quality of life was assessed by means of SF-36 questionnaire.[25] The Hospital Anxiety and Depression Scale (HADS) was also used in this work.[26] All were recorded twice: before treatment and after 5 sessions of biofeedback. Statistical processing of the research results was carried out in Excel 2007 and Statistica 13. The laws of parameter distribution were established on the basis of the Kolmogorov-Smirnov criterion. Statokinetic parameters did not contradict the hypothesis of a normal distribution. Dispersions were compared with Fisher F-test. For equality of variances, Student's t-test was used, with inequality, Welch's T-test was used. The parameters of quality of life and the hospital scale of anxiety and depression were compared on the of the Kraxler-Wallis test. The Spearman correlation coefficient was

Table 1. *Characterization of patients included in the study*

Age	Men		Women		Total
	Absolute number	Relative number	Absolute number	Relative number	
≤50	15	6.1%	17	6.9%	13.1%
51-60	28	11.4%	31	12.7%	24.1%
61-70	34	13.9%	65	26.5%	40.4%
≥71	24	9.8%	31	12.7%	22.4%
Total	97	41.2%	148	58.8%	100.0%

calculated. The differences with $p < 0.05$ were considered significant.

Results

The duration of stroke was 230 ± 42.1 days. The average age of the patients was 60.7 ± 11.6 years. There were 97 men, 148 women (Table 1). Ischemic stroke - 72.1%; hemorrhagic 27.9%. All the patients have showed hemispheric nidus localization: the right hemisphere - 44.9%; the left one - 55.1%. After treatment, according to the results of stabilokinesiogram, there was a significant increase in the common center of pressure (CCP) and acceleration of the common center of pressure (ACCP) in the frontal and sagittal planes (Table 2). These changes are combined with the observed significant increase in the width and length of the ellipse. At the same time, the length of the stabilokinesiogram increases. However, this reduces the ratio of the length of the statokinesiogram to its area. The analysis of frequency characteristics of the stabilokinesiogram (Table 3) indicates a significant decrease in the proportion of high-frequency (non-directional) oscillations after. The increase in the patient's movement range described in Table 4 correlates with an increase in the extent of low-frequency oscillations ($r = 0.89$, $p < 0.001$) and a decrease in the extent of high-frequency oscillations ($r = -0.75$, $p < 0.001$). As per data shown in table 3, all the patients has shown a significant increase in speed. According to the Kraskler-Wallis criterion, after treatment, the quality of life of patients on the SF-36 scale improved (Table 5). As a result of treatment, such indicators of life quality as physical functioning, role-based functioning, general health, and vitality increased. At the same time, the severity of pain decreased. The severity of depression and anxiety on the HADS scale also decreased. Negative correlations of the average strength between the speed of movement of patients in quadrants and the HADS scale were obtained (Table 6). Both before and after the treatment, patients with a higher score for depression or anxiety are characterized by a decrease in the speed of movement.

Table 2. *Change in the Linear Parameters of Stabilogram Before and After Sessions*

Parameter	before		after		p
	Average	Error average	Average	Error average	
Maximum amplitude of oscillations of the common center of pressure in frontal plane, mm	17.3	1.0	23.4	1.3	0.000
Maximum amplitude of oscillations of the common sagittal pressure center in plane, mm	25.4	1.2	30.2	1.1	0.004
Maximum amplitude of acceleration oscillations of the common center of pressure in frontal plane, mm	0,584	0,034	0,795	0,043	0,000
Maximum amplitude of acceleration oscillations of the common center of pressure in sagittal plane, mm	0.862	0.041	1.029	0.041	0.005
Length of statokinesiogram,	646.6	21.8	971.6	48.5	0.000
Ellipse length, mm	17.80	0.94	21.61	0.96	0.006
Ellipse width, mm	10.32	0.57	12.95	0.61	0.002
Ratio of length of statokinesiogram to its area	7.35	0.40	6.07	0.34	0.022
The ratio of the length of the statokinesiogram to its area	7.351	0.405	6.073	0.343	0.022

Table 3. *Change of Stabilogram Frequency Parameters Before and After Sessions*

Parameter	before		after		p
	Average	Error average	Average	Error average	
Amplitude of the 1st maximum of the spectrum along the frontal component, mm	0.831	0.075	1.196	0.090	0.002
Frequency of the 2nd maximum of the spectrum by the frontal component, hertz	0.284	0.017	0.218	0.016	0.007
Amplitude of the 2nd maximum of the spectrum along the frontal component, mm	0.611	0.040	0.838	0.056	0.001
Amplitude of the 3d maximum of the spectrum along the frontal component, mm	0.457	0.024	0.657	0.047	0.000
Frequency of the 3rd maximum of the spectrum for the sagittal component, hertz	0.339	0.017	0.426	0.021	0.001
Frequency of the 1st spectrum maximum along the vertical component, hertz	4.486	0.198	3.623	0.228	0.005
Amplitude of the 1st maximum of the spectrum along the vertical component, mm	0.022	0.001	0.030	0.005	0.048
Frequency of the 2nd spectrum maximum along the vertical component, hertz	4.626	0.198	3.574	0.222	0.001
Frequency of the 3d spectrum maximum along the vertical component, hertz	4.772	0.181	3.989	0.209	0.005
The level of 60% of the spectrum power by the vertical component, watts	5.88	0.09	5.32	0.12	0.000

Discussion

The main problem in the rehabilitation of stroke patients is the assessment of likelihood of their fall. Currently, there is no single test or methodological approach that would show the likelihood of falls after ADCC. The Berg Balance Scale is the commonly used clinical assessment to determine the risk of falls after a stroke.[27,28] There are works dedicated to studies of relationship between patient's movement speed and likelihood of falling. It has been shown that even if patients move at a convenient pace, this does not reduce the risk of falling. However, patients who move faster after a stroke have a lower risk of falling than those who move slowly.[29] Wearing comfortable shoes does not significantly affect the risk of falling.[30] Gait speed (for example, in a 10-meter walk test) is a common instrumental assessment to determine the risk of falls after stroke.[31] Measures of step variability and "smoothness" during gait were more informative in determining the likelihood of falls after a stroke than other clinical measurements.[32] However, a number of researchers believe that to assess the risk of falls it is necessary to simultaneously use both clinical scales and methods of balance assessment.[33] A number of works show the relationship between the equilibrium function and the fall after a stroke.[34-36] Also important is the change in position of the body balance in space. Thus, people who had a stroke showed a greater displacement of the pelvis in walking compared with healthy ones.[37] Based on the available publications, in a systematic review it is proposed to use the ratio of mobility and balance variables.[15] That is why in the course of our research we have studied both the indicators of stabilometry and the speed of patients' movement. We have found a decrease in the ratio of the length of statokinesiogram to its area, which can be regarded as a positive clinical factor.[38] As a result of rehabilitation, we have observed a decrease in the proportion of high-

Table 4. Changing in parameters of the patient's movement speed before and after exercise.

Parameter	before		after		p
	Average	Error average	Average	Error average	
Average speed quadrant I, mm / s	19.54	0.73	22.05	0.62	0.013
Average speed quadrant II, mm/ s	20.71	0.72	23.90	0.64	0.023
Average speed quadrant III, mm/ s	21.86	1.60	51.89	0.64	0.000
Average speed quadrant IV, mm/ s	18.91	0.68	21.65	0.68	0.006

Table 5. Changing in parameters of the patient's movement speed before and after exercise.

Parameter	before		after		p
	Average	Error average	Average	Error average	
Scale SF-36					
Physical functioning, points Role functioning, points	58.58	2.19	68.24	2.01	0.016
Role functioning, points	27.54	3.66	47.29	3.98	0.004
Pain, points	44.52	1.99	31.62	2.42	0.001
General health, points	46.52	9.63	48.64	10.45	0.238
Vitality, points	49.25	1.76	58.24	2.12	0.008
Social functioning, points	56.33	10.54	52.86	7.94	0.063
Emotional functioning, points	41.64	9.84	55.81	4.01	0.054
Psychological health, points	57.97	6.66	63.45	2.06	0.090
Scale HADS					
Anxiety, points	9,189	0,374	7,324	0,376	0,007
Depression, points	7,108	0,322	5,648	0,325	0,015

frequency movements against the background of an increase in speed of movement due to low-frequency movements to maintain the patient's static posture. In addition, we have ascertained an improvement in the patients' quality of life. This allowed us to make a preliminary conclusion about positive influence of the effected intervention on patients' condition. It should be noted that, according to several authors, dynamic balance estimates were better predictors of falls than static ones.[39] It is believed that the dynamics of maintaining patient's equilibrium can serve as a highly informative assessment to determine the risk of falling.[40] That is why, from our point of view, the most favorable predictor of positive changes in the condition of the examined patients is the positive dynamics of studied indicators. Methods of rehabilitation of stroke patients. Many methods are used to rehabilitate stroke patients. Especially relevant is the prevention of falls. According to a systematic review.[41] there is currently no effective evidence that physical rehabilitation methods can reduce the risk of falling after a stroke. There are preliminary results of the effectiveness of vitamin D, but they need a wider clinical study. Among the methods that are used for the rehabilitation of patients with ADCC, a decent place is based on the principle of biofeedback. Biofeedback (BFB) is an instrumental therapy method that allows the patient to come to understanding and controlling the reactions of his own body.[42] The method of biofeedback is widely used to treat a wide variety of conditions, such as clinical pathologies, its effectiveness has been proven to affect the functional capabilities of the brain, and there is evidence of its effect on the psychophysiological characteristics of patients.[43] During sessions, the patient makes various movements, and now the study of the relationship between psychology and movements is becoming increasingly relevant. There are works dedicated to the psychology of breathing, music and movement, as well as those that study smaller aspects - for example, eye movements.[44] Various techniques using biofeedback are widely used for the rehabilitation of patients after a stroke and ADCC. They can improve the body balance in space and reduce the number of falls.[45] For example, it is proposed to use the virtual reality method, which reduces the risk of falls in stroke patients.[46] Sensi-steps application is based on the principle of biofeedback, which reduces the risk of falls in stroke patients[47] A similar principle underlies the telemedicine rehabilitation of patients after ADCC.[48] Robotic methods and others are used.[21,49] The effectiveness of a number of rehabilitation methods has been evaluated in systematic reviews.[50-52]

Study limitations: The patients were monitored in a short time period. In the future, when monitoring the same cohort of patients, it is expected to evaluate the long-term

***Table* 6.** Coefficients of correlation of indicators on the HADS scale and patient movement speeds in quadrants.

Parameters		Quadrant travel speed			
Observation time	HADS scale parameters	I	II	III	IV
Before treatment	Anxiety	-0.74	-0.79	-0.73	-0.70
	Depression	-0.71	-0.75	-0.79	-0.84
After treatment	Anxiety	-0.83	-0.81	-0.88	-0.81
	Depression	-0.70	-0.78	-0.78	-0.86

results of the study of the effect of the biofeedback method on the stability of the posture of stroke survivors. In conclusion, the data obtained in this work tentatively show effectiveness of biofeedback method in rehabilitation of stroke patients. The technique allows to improve the equilibrium indicators and increase the speed of patients' movement.

List of acronyms

ADCC - acute disturbance of cerebral circulation
HADS - hospital anxiety and depression scale
CCP - common center of pressure
ACCP - acceleration of the common center of pressure.

Contributions of Authors

VZ conception and design of the study. AO and AR acquisition, analysis and interpretation of data. KG wrote the manuscript. KK performed literature review. VM and DS article drafting and revision. AF reviewed and edited the manuscript critically, all authors approved the final version.

Acknowledgments

None.

Funding

This research did not received any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

None

Ethical Publication Statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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Submission: September 18, 2020
Revision submitted: July 31, 2021
Accepted for publication: August 13, 2021