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POST-STROKE MOTOR IMPAIRMENTS: THE POSSIBILITIES OF INNOVATIVE TECHNOLOGIES AND THE RESULTS OF THE OWN RESEARCH

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SUMMARY

Introduction.*The article presents an overview of innovative technologies based on methods sensomotor retraining of the patient using neuromuscular electrical stimulation (NFES) and biofeedback (BFB) as the most promising in the medical rehabilitation (MR) of motor impairment in patients with brain stroke (BS). The results of our own study are also presented.*

The aim of the study *- an assessment of the effectiveness of a comprehensive rehabilitation program with the inclusion of NFES and stabilometric postural control using the BFB method in patients with after-stroke motor disfunction in the chronic ischemic stroke (IS).*

Material and methods. *We examined 87 patients (41 women and 46 men) in the chronic IS, mean age 58.4±6.4 years. The stroke duration was 228.59±31.9 days. The main group included 52 patients who, along with the standard treatment regimen, underwent NFES and BFB-stabilometric training. The comparison group consisted of 35 patients whose rehabilitation complex did not include the above methods.*

Results and conclusion. *Due to comlex rehabilitation with NFES and BFB stabilometric postural training it has been improved the function of walking. The clinical effect was noted 3 weeks after the start of rehabilitation, reaching a maximum by the 5th week. The inclusion of BFB-based methods in the medical rehabilitation leads to earlier motor and social adaptation of the after-stroke patient, restoration of the impairment balance function, which is associated with an increase in neuroplasticity.*

KEYWORDS: *stroke, motor disorders, rehabilitation, neuromuscular electrical stimulation, biofeedback.*

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Loss of functional movement and coordination are the most common consequences of stroke which lead to disability [1–2]. Muscle weakness, abnormal muscle activity and muscle dyssynergia due to brain stroke (BS) cause walking function asymmetry and gait changes [3]. Motor deficit in central hemiparesis is also determined by the severity of spasticity, contractures and arthralgia.

Balance disorders after BS increase the risk of falls, make it difficult for patients` movement, reduce the level of daily activity and the restoration of walking function [4–6]. In addition, post-stroke cognitive impairment and depressive disorders associated with motor deficits slow down the rehabilitation process [7]. In general, post-stroke motor disfunction is associated with low quality of life and risk of premature death.

The gait of hemiplegic patients has very specific features [8–9]: reduced walking speed, increased double stance phase, and reduced amplitude of movement in the leg joints [10]. The common features of the hemiparetic gait include specific spatio-temporal patterns, including a decrease in the rotation frequency, an increase in the duration of the swing on the paretic side and the duration of the support, an asymmetry of the step length compared with the gait parameters of healthy subjects [11–12], a decrease in walking speed. There are four main gait abnormalities associated with hemiparesis [13]: the drop-foot gait, the circumduction gait, the hip hiking gait, and the back-knee gait.

The relevance of the topic and the current state of the problem

A universal factor in improving post-stroke motor impairments is physical activity, which is associated with the formation of new reciprocal and interhemispheric connections, increased neuroplasticity [1, 3, 14]. When muscle synergy in after-stroke patients were analyzed an improvement in the motor activity of the lower extremities, in particular, the module of the plantar flexor of the ankle joint during the rehabilitation period of BS against the background of walking training was shown [15]. In the most recent study on subacute stroke participants an increased lateral symmetry in muscle synergies while walking, associated with improvements in gait kinematics measurements, was found after 3 weeks of walking training supported by a lower limb exoskeleton [16].

Thus, repeated motor practice and motor activity in a real-world environment have been identified in several prospective studies as a favorable factor for restoring motor activity in after-stroke patients [17].

Neuromuscular functional electrical stimulation (NFES) of paretic muscles is the main additional method of therapy, usually used with kinesiotherapy (functional rehabilitation) and pharmacological treatment in patients after BS [1–4].

The therapeutic effect of electrical stimulation on muscle regeneration after the denervation from the spinal motor neuron level has been confirmed both in experimental animal studies [18] and in the rehabilitation of patients with upper motor neuron syndrome (consequences of spinal cord injury, BS and cerebral palsy). NFES has been shown to improve motor impairment in BS, probably by modifying neural transmission at the synaptic junctions of the corticospinal tract with spinal motor neurons. [19–20]. In addition, NFES promotes an increase in the number of motor units, which is closely associated with increasing muscle strength [21]. The available literature provides the specific effects of NFES, reflecting its important role in neuromodulation at the spinal and supraspinal levels in patients with BS [22]. Therapeutic applications of NFES include upper and lower limb motor relearning and reduction of poststroke shoulder subluxation and pain. Терапевтические аспекты применения НФЭС включают моторное переобучение верхних и нижних конечностей, уменьшение гемиплегической боли в плече, strengthening muscles and muscle atrophy preventing [23]. Stein et al. showed that combination of NFES and other methods reduced of spasticity and improvement of range of motion in patients after BS [24].

Probably, NFES can directly cause the transmission of a nerve impulse through biofeedback (biofeedback), causing modulation of the work of the inhibitory interneurone Ia, which controls the function of the antagonist muscles of the forearm and lower limb. The discoordination of these muscle groups is described as the most significant muscle dysfunction in patients with BS [25].

The effect of NFES of the neuromuscular apparatus on the walking function in after-stroke patients has been shown in many randomized clinical trials (RCTs) of recent years [26–32].

Sharif F et al. selected from 5066 articles of 29 RCTs involving 940 patients. NFES produced a reduction in spasticity (–0.30 [95% confidence interval,–0.58 to –0.03], n=14 RCTs) and an increase in range of motion compared with controls (2.87 [95% confidence interval, 1.18–4.56], n=13 RCTs) after BS. Gait training with NFES compared with standard electrical stimulation showed better results in terms of mobility, balance, gait performance and reduction of spasticity in patients with BS [26].

The effectiveness of NFES in combination with other rehabilitation methods has been proven in another review. It was shown the reducing of the spasticity and increasing the range of motion in patients after BS. [24].

In 2018, 21 RCTs were selected from 5759 articles with 1481 participants. The combined analysis showed that NFES has a moderate but statistically significant effect on the motor function of the lower extremities (standard mean difference 0.42, 95% confidence interval 0.26–0.58), especially when combined with other rehabilitation methods for 6 or 12 weeks trainings. Significant changes in gait speed, balance, spasticity and range of motion were also noted, but there were no differences in walking endurance during NFES [27].

In the most recent studies of Cochrane Library, MEDLINE, EMBASE, CINAHL, AMED, PsycINFO, WOS, Scopus, OpenGrey and 4 Chinese databases with only RCT analysis, the results of the NFES-using in combination with motor activity for the treatment of patients with post-stroke spastic hemiparesis are summarized [28].

Thus, NFES contributes to an increase in muscle strength and a change in the pathological motor stereotype. It allows to restore impaired motor skills by improving muscle condition and correctly performed movements relearning.

The optimal NFES algorithm uses stimulation frequencies of about 15 Hz for applications on the upper extremities and about 20 Hz for applications on the lower extremities. Modified frequencies with proven effectiveness range from 10 to 50 Hz; sessions are usually conducted five times a week for 3–8 weeks [29–32].

Proprioceptive sensory feedback may play an important role in neuromuscular stimulation. This is confirmed by studies of multichannel near-infrared spectroscopy for non-invasive and dynamic measurement of hemoglobin levels in the brain. Cerebral blood flow in the sensorimotor cortex on the injured side was higher during the NFES session than during simple active movement or simple electrical stimulation. [17].

On this point, biofeedback (BFB) technology becomes promising for training the walking function. It involves recording a certain physiological parameter (walking parameters) and presenting it in an obvious form for the patient so that the latter can navigate in its change and correct the given parameter. BFB therapy is currently considered as an effective independent method of MR in patients after BS, successfully combined with other intervention modalities. Biofeedback provides real-time information about physiological processes that may not be visible to the patient, allowing awareness and self-correction of abnormal gait patterns [33]. BFB can be carried out with the help of various sensory organs, such as visual, auditory, tactile or a combination of different methods. Different modes of BFB can have different effects on efficiency and motor skills training [34–35]. Significant progress has been made with the initial use of BFB on single muscle electromyography to improve gait in hemiparesis after BS [36]. Real-time BFB reflecting limb positioning or muscle strength during walking aims to improve walking function when post-stroke hemiparesis [37]. Thus, after two weeks of training on a treadmill with a visual BFB with step length, after-stroke patients demonstrated improvements in step length, incl. at 6-month follow-up [37]. Ki at al. noted a significant improvement in step length and support response of the paretic lower limb during training with BFB while walking in stroke patients [37]. The use of audiovisual BFB targeting anterior ground reaction forces (AGRF) can cause a significant improvement in AGRF in the paretic leg without changing this option in the non-paretic low limb [38]. Despite the proven effectiveness of BFB in restoring specific gait impairments of the paretic lower limb in after-stroke patients, the modes of BFB, as well as strategies for improving gait and motor retraining, are not clearly defined.

According to the literature, the inclusion of NFES or BFB-stabilometric training in the complex rehabilitation of patients in the early recovery period of BS is more effectively increase daily activity compared with standard methods, such as traditional kinesiotherapy [1, 3–4, 24–25].

Our study focused on the use of NFES in combination with BFB-stabilometric postural control in the recovery of patients with post-stroke stato-locomotor disturbances. This approach is not presented in the literature.

Purpose of the study: to evaluate the effectiveness of a complex rehabilitation program with NFES and BFB-stabilometric postural control in patients with post-stroke motor disturbances in the chronic period of ischemic stroke (IS).

Material and methods

The study included 87 patients in the chronic period of IS, 41 women and 46 men, aged 45 to 75 years (mean 58.4±6.4 years). The duration of a stroke ranged from 181 to 356 days, averaging 228.59±31.9 days; patients with a stroke duration of 180–272 days prevailed (71.2 %). Hemispheric localization of the lesion was observed in all patients: in the right hemisphere – in 44.8 %; in the left – in 55.2 %; The diagnosis was verified by CT or MRI of the brain. The main reasons for the development of IS were hypertension, atherosclerosis, and their combination.

The inclusion criteria for the study were: age from 45 to 75 years; the presence of mild or moderate monoparesis of the lower limb/hemiparesis; chronic period of IS, the patient's ability to independently (without support) maintain balance when standing for at least 2 minutes, mild cognitive disorders, the absence of the osteoarticular system pathologies and severe visual impairment that prevent the study; signed informed consent.

The exclusion criteria were: the presence of an implantable pacemaker; benign and malignant neoplasms; epilepsy; somatic diseases decompensation; unstable angina and paroxysmal cardiac arrhythmias; increased excitability of the patient, intolerance to minimal electrical irritations; the impossibility of obtaining a contraction of the muscles of the lower limb under electrical action within the limits of tolerable pain sensations; acute neurological diseases of the spinal cord and its roots; acute infectious diseases; acute thrombophlebitis of deep and superficial veins of low limbs; the muscle contractures in the knee and ankle joints; lower paraparesis; pregnancy and lactation.

All patients received medical therapy according to the standards of specialized medical care; physical therapy, kinesiotherapy, psychotherapy.

The subjects were randomly divided into 2 groups.

The first, *main group* included 52 patients with chronic IS, who underwent NFES and BFB-stabilometric training.

Table 1

Methods used in the study

Studied function	Examination methods
State of the locomotor system	The 6-point Medical Research Council Scale for assessing muscle strength: MRCS; Modified Ashworth Scale: MAS (0 to 4 points), 10 meter walking test
Postural disturbances	Tinetti scale stabilometry
Comprehensive assessment of motor function	Walking Difficulty Global Score – On a scale of 1 (no sign) to 4 (most severe), the following characteristics of the patient's walking are assessed: unsteadiness, effort required to walk, impression of pain, difficulty moving in general; biomechanics of movements
Cognitive functions	MMSE (Mini-Mental State Examination)
Presence and severity of depression	Hospital Anxiety and Depression Scale HADS
Functional independence	Index Barthel
Life quality assessment	EuroQol EQ-5D-5L (version 1.0, 2011)

The second *comparison group* consisted of 35 patients with IS, who did not include the two above–mentioned methods. The main group and the comparison group were the same age-sex composition, clinical manifestations.

The biomechanical study was performed on the Trust-M hardware and software system ('Nevrokor', Moscow). Methods of gait and main stance analysis were used – stabilometry. The gait was studied by temporal, kinematic parameters and support reactions. The NFES technique was carried out on the simulator 'Correction of Movements 'Trust M' ('Nevrokor', Moscow) according to the standard scheme. The duration of the training was 20–30 minutes, 15 sessions (3 times a week, 5 weeks).

The balance and movement impairments were corrected by the method of BFB-exercises on the stabiloplatform 'Trust-M' ('Nevrokor', Moscow). Romberg's test was carried out according to the European version of the installation of the feet (heels together, toes apart at an angle of 30 degrees) in 2 phases: with open (OE) and closed (CE) eyes. Each phase of the study lasted 30 seconds. For the comparison with the norm the general standard values proposed by D. V. Skvortsov were used [39]. It was used static ('Target') and dynamic ('Man') BFB-tests with an exposure of 20–30 minutes, 3 times a week for 5 weeks. The BFB- training was performed in the first half of the day, before the NFES, to minimize the impact of external factors. At the end of the BFB-training course control stabilometry study was performed for dynamics.

The examination was carried out at baseline, before the start of therapy (1st visit), after 3 weeks of therapy (2nd visit), after 5 weeks from the start of rehabilitation (3rd, final visit) using different methods and scales (*Table 1*). Side effects and adverse events were evaluated at each visit.

Statistical analysis of the data included a comparison of dependent and independent series of variables and methods of descriptive statistics. The type of data distribution was assessed using the Shapiro-Wilk test. Parametric quantitative data were represented by mean values and standard error of the mean (M±m). Nonparametric quantitative and rank variables were presented as median and interquartile range: IQR (Me [P25; P75]). The validity of differences was determined using Student's t-test. The differences between qualitative binary traits were assessed using the χ^2 criterion. The statistical significance level was accepted as p=0·05. Nonparametric Spearman correlation test was used to reveal the relationship between two features. The results obtained were processed using the licensed software Statistics 7.0 and Microsoft Excel.

Results

All patients completed the study.

At the initial examination, patients had pyramidal (from reflex to moderate hemi- and monoparesis) and sensory impairments (superficial sensitivity like hypo- and anesthesia), varying severity ataxia, as well as vestibular (both peripheral and central) disturbances.

A manual study revealed a deficiency of muscle function in the quadriceps, gluteal muscles (100 %), leg flexors (73.6 %), tibia (100 %) and gastrocnemius (67.8 %) muscles. Lameness, impaired transfer of the affected limb was noted in 100 % of cases; in 37.9 % of patients, foot rolling was impaired, 42.5 % of patients used additional means of support.

Changes in the biomechanics of gait in patients were nonspecific of a decrease in the pace of the step. In addition, functional consequences of insufficiency of the quadriceps femoral muscle in the form of passive closure of the knee joint and insufficiency of the triceps tibia muscle were found. It was shown a decrease in the amplitude of repulsion of the longitudinal component of the support reaction and a decrease in the amplitude of plantar flexion of the ankle joint; asymmetry of the periods of the step cycle; decreased stability, which was accompanied by a deviation of the center of pressure (CP) to the healthy side. The position of the CP in the sagittal plane was characterized by a forward displacement of about 9 mm. The oscillations of the CP exceeded the norm in both the frontal and sagittal planes; the area of the statokinesiogram exceeded the norm in both phases of the study. Patients' energy consumption was increased, especially during the CE-phase. In patients with lower monoparesis or hemiparesis, a significant changes in the standard deviation of the CP in the frontal plane were regarded as a markers of pathological posture (the transfer of the center of gravity to a healthy 'nonparetic' limb or, in some cases, to the affected limb with a moderate degree of spasticity).

When assessing postural disorders on the Tinetti scale, mild motor disorders were detected in 63.2 % and moderate – in 36.8 % of cases. After a course of medical rehabilitation (MR) positive dynamic was observed in patients of both groups. There were an increase in strength in the paretic limb, its involvement in the process of orthostasis. The difference of tendon reflexes, the severity of the vestibuloatactic syndrome decreased. Balance tests and the patient's stability in the Romberg position were normalized.

After 5 weeks it was shown a decrease in spasticity scores according to the Ashworth scale in the distal lower limb. However, these changes were not statistical significance (p>0.05). At the end of the course of NFES there were the increase in muscle strength averaged 0.5–1 point, in 54.7 % of patients at the time of the procedure, a more correct foot placement on the support.

By the 5th week of therapy, a statistically significant increase in walking speed was observed in patients of the main group (from 73.6 to 56.2 s; p<0.05).

A study of the Global assessment of walking difficulties after 5 weeks MR revealed a statistically significant improvement in all indicators (*Table 2*).

Table 2

Dynamics of indicators of the Global assessment of difficulty in movement scale in complex rehabilitation of post-stroke patients (number of patients, %)

The period of MR	Instability, unsteadiness of gait	Application of efforts	Pain	General walking difficulties
Main group (n=52)				
Before MR				
4 points	–	–	7,1	–
3 points	52,3	81	26,2	47,7
2 points	47,7	19	66,7	52,3
1 point	–	–	–	–
3 weeks				
4 points	–	–	–	–
3 points	45,3	66,7	33,3	42,9
2 points	54,7	33,3	66,7	57,1
1 point	–	–	–	–
p	0,19	1,0	0,46	0,07
χ2	1,67	0,0	0,53	3,13
5 weeks				
4 points	–	–	–	–
3 points	33,3	57,1	9,6	26,2
2 points	66,7	42,9	83,3	73,8
1 point	–	–	7,1	–
p	<0,001*	<0,001*	<0,001*	<0,001*
χ2	7,68	13,4	22,8	7,03
Comparison group (n=35)				
Before MR				
4 points	–	–	8	–
3 points	52	80	28	48
2 points	48	20	64	52
1 point	–	–	-	-
3 weeks				
4 points	–	–	4	–
3 points	48	68	28	40
2 points	52	32	68	60
1 point	–	–	-	–
p	0,57	0,052	0,5	0,25
χ2	0,3	3,72	1,455	1,3
5 weeks				
4 points	–	–	–	–
3 points	32	58,0	20	28
2 points	68	42,0	76	72
1 point	–	–	4	–
p	0,005*	<0,001*	0,003*	0,004*
χ2	8,2	0,53	14,33	8,5

Note: the reliability of the differences is p – initially and at a certain point in the study; * p<0.05.

Functional movement improvement was confirmed by the results of the Tinetti scale. In patients of the main group, mild and moderate statolocomotor disturbances were registered in 52.3 % and 9.5 % of cases; normal motor activity was recorded in 38.2 % of patients. In the comparison group, these figures were 68 %, 12 % and 20 %, respectively.

Posturological parameters in the main group after complex NFES and BFB- stabilometric training rehabilitation were presented in Table 3. There was a significant (p<0.05) decrease in the area of the statokinesiogram and a decrease in the deviation of the total CP in the sagittal plane. Such a result can be considered as an objective increase in the stability of patients. The Romberg coefficient decreased, which indicated the restoration of deep proprioceptive sensitivity. In patients with low-limb paresis, the index of the position of the common CP in the frontal plane improved (p<0.05) when performing functional tests (regression of paresis and postural asymmetry). There was a trend towards a decrease in the speed of movement of the CP (indicator of general stability). Thus, the stabilogram restructuring coincided with the clinical regression of statolocomotor impairments.

In the comparison group, a positive dynamics of indicators was also observed (*Table* 3). The CP leveled out in both planes (significantly along the X axis), the area of the statokinesiogram decreased, the speed of CP movement decreased, the Romberg coefficient normalized significantly. These changes indicated a decrease in paresis and an increase in the overall stability of patients. By the end of the study in the main group, the length of the statokinesiogram decreased by an average of 27.4 % with OE and by 30 % with CE (596.77±89.6) and the area of the statokinesiogram decreased by 50.7 % compared with the beginning of treatment (p <0.05). In the comparison group the changes were not statistically significant.

In general, the data obtained indicate a more pronounced improvement in resistance parameters in main group patients.

Table 3

Dynamics of motor disfunction during complex rehabilitation of post-stroke patients of two groups

Data	Before	5 weeks	p
Main group (n=52)			
Tinetti scale, total score	19,3 ± 3,4	27,4 ± 2,8	p=0,045*
Tinetti scale, stability subscale, points	10,2 ± 2,8	15,72 ± 2,65	p=0,2
Tinetti scale, gait subscale, points	9,66 ± 3,45	11,63 ± 3,2	p=0,67
Length of the statokinesiogram, mm	**852,53 ±84,3**	**618,12 ± 91,2***	**0,049**
Area of the statokinesiogram, mm²	**576,7 ± 93,6**	**292,2 ± 100,2***	**0,049**
Area of the statokinesiogram, mm² (CE)	**576,44±53,63**	369,42±62,22	**0,014**
Frequency of oscillations in the sagittal plane, Hz	1,27 ± 0,36	1,14 ± 0,41	0,84
Frequency of oscillations in the frontal plane, Hz	2,78 ± 0,86	2,16 ± 0,92	0,65
Romberg Coefficient	**55,8±6,81**	**95,2±6,47***	**p=0,002**
Группа сравнения (n=25)			
Tinetti scale, total score	19,8 ± 2,8	25,4 ± 2,7	p=0,15
Tinetti scale, stability subscale, points	10,5 ± 3,0	14,58 ± 2,95	p=0,4
Tinetti scale, gait subscale, points	9,8 ± 3,1	11,33 ± 3,0	p=0,7
Length of the statokinesiogram, mm	872,53 ± 92,07	699,71 ± 98,23	0,21
Area of the statokinesiogram, mm²	554,7 ± 100,5	309,47 ± 101,8	0,09
Area of the statokinesiogram, mm² (CE)	581,4±53,63	471,74±58,6	0,17
Frequency of oscillations in the sagittal plane, Hz	1,3 ± 0,42	1,24 ± 0,36	0,92
Frequency of oscillations in the frontal plane, Hz	2,79 ± 1,01	2,30 ± 1,09	0,78
Romberg Coefficient	56,9±6,88	73,1±6,6	0,09

Note: the reliability of the differences is p – initially and at a certain point in the study; * p<0.05.

As a result of the MR, there was a positive dynamics in the neurodynamic (p>0.05) and regulatory functions (p>0.05) in patients of both groups. There were no intergroup differences in the total MMSE score in the two groups throughout the study (p>0.05).

The assessment of psychoemotional disturbances by the HADS scale revealed 12 patients with moderate anxiety (13.7%); 55 patients (63.2%) with mild anxiety and depressive disorders and 12 patients (13.7%) with 'obvious' depression. Moderate impairments of the anxiety-depressive series were present in patients with severe motor disfunctiuon that reduce daily activity and the ability to self-care. After 5 weeks of MR, the average score of anxiety and depression on the HADS scale decreased in most patients (Table 4). Changes in anxiety and depression indicators on the HADS scale were associated with improved walking characteristics.

Statistically significant dynamics of the Bartel index total in patients of the main group was due to an increase in movement criteria scores (climbing stairs – 46% increase in 5 weeks, transplanting – 40%, walking – 80.6%) and self-service skills (eating 54% increase in 5 weeks, taking a bath – 60%, using toilet – 46%). In the comparison group, similar dynamics were observed but were not statistically significance.

A similar dynamic was observed in quality of life questionary. In the main group, the changes reached a degree of statistical significance.

The overall Bartel score significantly correlated with the HADS score (r= –0.68, p<0.05) and MMSE (r=0.49, p<0.05) after 5 weeks of MR The overall score of the EQ-5D scale after 5 weeks significantly correlated with the MMSE score (r=0.47; p<0.05), the HADS depression subscale after 5 weeks of MR(r= –0.28; p<0.05).

During NFES and BFB-training there was no destabilization of systemic hemodynamics. So, this technology can be used in patients with cardiovascular diseases.

Discussion

BS often leads to motor impairments characterized by a mediolateral deviation towards the intact lower limb and greater instability of the PC [40]. These dysfunctions lead to balance disorders [4, 8–11], which are responsible for an increased risk of falls and a lower level of activity and participation in stroke patients [10–11]. Balance is associated with the ability to move and the quality of life [40]. Moreover, balance is a predictor of the possibility of walking recovery, and is also potentially changed by physical activity [4, 8–11, 40]. The development of rehabilitation technologies to improve balance and walking function is relevant for patients with BS.

The necessary stability in the vertical position of post-stroke patients is realized by consistent training of patients in standing and walking conditions. A MR-complex with the inclusion of NFES and BFBstabilometric postural training significantly improve the function of walking by the restoring a motor stereotype and the correct placement of the foot on the support. The clinical effect was observed 3 weeks after the start of MR, reaching a maximum by the 5th week. There was a decrease in the severity of pain in the paretic limb. The game accent during the use of BFB required mental efforts from the patient. Thus, there were shown significant positive changes in impaired cognitive functions, as well as indicators of anxiety and depression after the course of NFES and BFB-training.

In the study, there were improved limb support, increased walking speed, exercise tolerance, improved psychoemotional state and quality of life of the after-stroke patients.

Conclusions

1. The patients in the chronic period of IS demonstrate a pathological type of stance, which is confirmed by deviations in computer stabilometry. Deviation of the common

CP in the frontal plane indicates the presence of paretic disorders; an increase in the area of the statokinesiogram confirms the presence of atactic syndrome.

2. The stabilometric estimation indicates the high effect of rehabilitation training with stabilometric platform in achieving static stability in patients in the chronic period of a IS.
3. The effect of complex NFES and BFB-stabilometric training in the chronic period period of a stroke is confirmed by the Tinetti scale: in 67% of cases, gait and standing process are normalized in patients with mild disorders, which is 2 times higher than in the group comparisons.
4. The BFB-based methods in the complex rehabilitation leads to earlier social adaptation of the patient and restoration of the impaired balance function.

The positive effect of complex rehabilitation with the NFES and BFB-computer stabilometry on statolocomotor disfunction in patients in the chronic period of IS has been proven. The study justifies its use in the MR of an after-stroke motor defect.

References

1. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. Lancet Neurol. 2009;8(8):741–754. doi:10.1016/S1474–4422(09)70150–4.
2. Berge E, Whiteley W, Audebert H, et al. European Stroke Organisation (ESO) guidelines on intravenous thrombolysis for acute ischaemic stroke. Eur Stroke J. 2021;6(1): I–LXII. doi:10.1177/2396987321989865.
3. Rabadi MH. Review of the randomized clinical stroke rehabilitation trials in 2009. Med Sci Monit. 2011;17(2): RA25-RA43. doi:10.12659/msm.881382ю
4. Tappakhov AA, Konnikova EE, Argunova OG, Nikanorov VN, Dmitrieva NG. Stabilometry in the diagnosis and treatment of acute disorders of cerebral circulation: a pi lot study. Materials of the III Republican Scientific and Practical Conference 'Improving the Provision of Medical Aid to Patients with Vascular Diseases in the Republic of Sakha (Yakutia)'. 2016;43–46. (In Russ.).
5. Norrving B, Kissela B. The Global Burden of Stroke and Need for a Continuum of Care. Neurology. 2013;80(3 suppl 2):5–12.https://doi.org/10.1212/wnl.0b013e3182762397.

Table 4

Dynamics of data on the MMSE, HADS scales, indicators of functional independence and quality of life during MR in patients of the main and comparison groups

Groups	Points		
	Before MR	3 weeks	5 weeks
MMSE			
Main (n=52)	22,9±1,7	24,6±1,6	25,8±1,4
Comparison (n=35)	23,1±1,3	23,6±1,4	24,9±1,2
Anxiety			
Main (n=52)	9,7±2,8	7,9±3,5	7,4±3,3
Comparison (n=35)	9,3±2,9	8,9±3,3	8,7+3,5
Depression			
Main (n=52)	9,9±2,7	8,3±3,4	7,8±3,5
Comparison (n=35)	9,6±3,1	8,7±3,2	8,5+3,2
Index Barthel			
Main (n=52)	58,2±2,8	-	75,5±3,7*
Comparison (n=35)	58,9±2,9	-	62,7±2,7
EQ-5D, VAS			
Main (n=52)	46,3±2,3	-	61,2±3,0*
Comparison (n=35)	46,8±2,4	-	53,4±2,8

Note: the reliability of the differences is p – initially and at a certain point in the study; * p<0.05.

6. Kleim JA, Barbay S, Cooper NR, et al. Motor learning-dependent synaptogenesis is localized to functionally reorganized motor cortex. Neurobiol Learn Mem. 2002;77(1):63–77. doi:10.1006/nlme.2000.4004.
7. Blümle A, Maurer C, Schweigart G, Mergner T. A Cognitive Intersensory Interaction Mechanism in Human Postural Control. Exp Brain Res. 2006; 173(3):357–363. https://doi.org/10.1007/s00221–006–0384-z.
8. Perry J. Gait Analysis: Normal and Pathological Function. Slack Incorporated; Thorofare, NJ, USA: 1992.
9. Chen G., Patten C., Kothari D.H., Zajac F.E. Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. Gait Posture. 2005;22:51–56. doi: 10.1016/j.gaitpost.2004.06.009.
10. Boudarham J., Roche N., Pradon D., Bonnyaud C., Bensmail D., Zory R. Variations in Kinematics during Clinical Gait Analysis in Stroke Patients. PLoS ONE. 2013;8: e66421.doi: 10.1371/journal.pone.0066421
11. Roth EJ, Merbitz C, Mroczek K, Dugan SA, Suh WW. Hemiplegic gait. Relationships between walking speed and other temporal parameters. Am J Phys Med Rehabil. 1997;76(2):128–133. doi:10.1097/00002060–199703000–00008.
12. Alexander LD, Black SE, Patterson KK, Gao F, Danells CJ, McIlroy WE. Association between gait asymmetry and brain lesion location in stroke patients. Stroke. 2009;40(2):537–544. doi:10.1161/STROKEAHA.108.527374
13. Chantraine F, Filipetti P, Schreiber C, Remacle A, Kolanowski E, Moissenet F. Proposition of a Classification of Adult Patients with Hemiparesis in Chronic Phase. PLoS One. 2016;11(6): e0156726. Published 2016 Jun 7. doi:10.1371/journal.pone.0156726.
14. Ambrosini E, Parati M, Peri E, et al. Changes in leg cycling muscle synergies after training augmented by functional electrical stimulation in subacute stroke survivors: a pilot study. J Neuroeng Rehabil. 2020;17(1):35. Published 2020 Feb 27. doi:10.1186/s12984–020–00662-w.
15. Bowden Mark G., Clark David J., Kautz Steven A. Evaluation of Abnormal Synergy Patterns Poststroke: Relationship of the Fugl-Meyer Assessment to Hemiparetic Locomotion. Neurorehabilitation and Neural Repair. 2009;24(4):328–337. doi: 10.1177/1545968309343215.
16. Tan CK, Kadone H, Watanabe H, Marushima A, Yamazaki M, Sankai Y, et al. Lateral symmetry of synergies in lower limb muscles of acute post-stroke patients after robotic intervention. Front Neurosci. 2018;12:1–13. doi: 10.3389/fnins.2018.00276
17. Hara Y. Neurorehabilitation with new functional electrical stimulation for hemiparetic upper extremity in stroke patients. J Nippon Med Sch. 2008;75(1):4–14. doi:10.1272/jnms.75.4.
18. Kern H., Salmons S., Mayr W., Rossini K., Carraro U. Recovery of long-term denervated human muscles induced by electrical stimulation. Muscle Nerve. 2005;31:98–101. doi: 10.1002/mus.20149.
19. Sheffler L.R., Chae J. Neuromuscular electrical stimulation in neurorehabilitation. Muscle Nerve. 2007;35:562–590. doi: 10.1002/mus.20758.
20. Monte-Silva K., Piscitelli D., Norouzi-Gheidari N., Batalla M.A.P., Archambault P., Levin M.F. Electromyogram-Related Neuromuscular Electrical Stimulation for Restoring Wrist and Hand Movement in Poststroke Hemiplegia: A Systematic Review and Meta-Analysis. Neurorehabil. Neural Repair. 2019;33:96–111. doi: 10.1177/1545968319826053.
21. Marotta N., Demeco A., Inzitari M.T., Caruso M.G., Ammendolia A. Neuromuscular electrical stimulation and shortwave diathermy in unrecovered Bell palsy: A randomized controlled study. Medicine. 2020;99: e19152. doi: 10.1097/MD.0000000000019152.
22. Rushton D. Functional electrical stimulation and rehabilitation: A hypothesis. Med. Eng. Phys. 2003;25:75–78. doi: 10.1016/S1350–4533(02)00040–1.
23. Chae J, Sheffler L, Knutson J. Neuromuscular electrical stimulation for motor restoration in hemiplegia. Top Stroke Rehabil. 2008;15(5):412–426. doi:10.1310/tsr1505–412.
24. Stein C, Fritsch CG, Robinson C, Sbruzzi G, Plentz RD. Effects of Electrical Stimulation in Spastic Muscles After Stroke: Systematic Review and Meta-Analysis of Randomized Controlled Trials. Stroke. 2015;46(8):2197–2205. doi:10.1161/STROKEAHA.115.009633.
25. Huber J, Kaczmarek K, Leszczyńska K, Daroszewski P. Post-Stroke Treatment with Neuromuscular Functional Electrostimulation of Antagonistic Muscles and Kinesiotherapy Evaluated with Electromyography and Clinical Studies in a Two-Month Follow-Up. Int J Environ Res Public Health. 2022 Jan 15;19(2):964. doi: 10.3390/ijerph19020964. PMID: 35055785; PMCID: PMC8775942.
26. Sharif F, Ghulam S, Malik AN, Saeed Q. Effectiveness of Functional Electrical Stimulation (FES) versus Conventional Electrical Stimulation in Gait Rehabilitation of Patients with Stroke. J Coll Physicians Surg Pak. 2017;27(11):703–706.
27. Hong Z, Sui M, Zhuang Z, et al. Effectiveness of Neuromuscular Electrical Stimulation on Lower Limbs of Patients With Hemiplegia After Chronic Stroke: A Systematic Review. Arch Phys Med Rehabil. 2018;99(5):1011–1022.e1. doi:10.1016/j.apmr.2017.12.019.

28. He YL, Gao Y, Fan BY. Effectiveness of neuromuscular electrical stimulation combined with rehabilitation training for treatment of post-stroke limb spasticity. Medicine (Baltimore). 2019;98(39): e17261. doi:10.1097/MD.0000000000017261.
29. Sentandreu-Mañó T., Tomás J.M., Ricardo Salom Terrádez J. A randomised clinical trial comparing 35 Hz versus 50 Hz frequency stimulation effects on hand motor recovery in older adults after stroke. Sci. Rep. 2021;11:9131. doi: 10.1038/s41598–021–88607–8.
30. Billian C., Gorman P.H. Upper extremity applications of functional neuromuscular stimulation. Assist. Technol. 1992;4:31–39. doi: 10.1080/10400435.1992.10132190
31. Eraifej J, Clark W, France B, Desando S, Moore D. Effectiveness of upper limb functional electrical stimulation after stroke for the improvement of activities of daily living and motor function: a systematic review and meta-analysis. Syst Rev. 2017;6(1):40. Published 2017 Feb 28. doi:10.1186/s13643–017–0435–5.
32. Sabut S.K., Sikdar C., Kumar R., Mahadevappa M. Functional electrical stimulation of dorsiflexor muscle: Effects on dorsiflexor strength, plantarflexor spasticity, and motor recovery in stroke patients. NeuroRehabilitation. 2011;29:393–400. doi: 10.3233/NRE-2011–0717.
33. Stanton R, Ada L, Dean CM, Preston E. Biofeedback improves performance in lower limb activities more than usual therapy in people following stroke: a systematic review. J Physiother. 2017;63(1):11–16. doi:10.1016/j.jphys.2016.11.006.
34. Molier BI, Van Asseldonk EH, Hermens HJ, Jannink MJ. Nature, timing, frequency and type of augmented feedback; does it influence motor relearning of the hemiparetic arm after stroke? A systematic review. Disabil Rehabil. 2010;32(22):1799–1809. doi:10.3109/09638281003734359.
35. Sigrist R, Rauter G, Riener R, Wolf P. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review. Psychon Bull Rev. 2013;20(1):21–53. doi:10.3758/s13423–012–0333–8.
36. Wolf SL, Binder-MacLeod SA. Electromyographic biofeedback applications to the hemiplegic patient. Changes in lower extremity neuromuscular and functional status. Phys Ther. 1983;63(9):1404–1413. doi:10.1093/ptj/63.9.1404.
37. Liu J, Kim HB, Wolf SL, Kesar TM. Comparison of the Immediate Effects of Audio, Visual, or Audiovisual Gait Biofeedback on Propulsive Force Generation in Able-Bodied and Post-stroke Individuals. Appl Psychophysiol Biofeedback. 2020 Sep;45(3):211–220. doi: 10.1007/s10484–020–09464–1. PMID: 32347399; PMCID: PMC7447533.
38. Genthe K, Schenck C, Eicholtz S, Zajac-Cox L, Wolf S, Kesar TM. Effects of real-time gait biofeedback on paretic propulsion and gait biomechanics in individuals post-stroke. Top Stroke Rehabil. 2018;25(3):186–193. doi:10.1080/10749357.2018.1436384.
39. Skvortsov D.V. Clinical analysis of movements. Gait analysis: Publishing house NPC – 'Stimulus', Ivanovo, 1996.– 344 p.
40. Skvortsov DV, Kaurkin SN, Ivanova GE. A Study of Biofeedback Gait Training in Cerebral Stroke Patients in the Early Recovery Phase with Stance Phase as Target Parameter. Sensors (Basel). 2021;21(21):7217. Published 2021 Oct 29. doi:10.3390/s21217217

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FEATURES OF HUMAN MICROFLORA AND LOCAL IMMUNITY IN AN ARTIFICIAL ENVIRONMENT

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SUMMARY

The article shows the role of extreme influences on the development of pathological changes in the dento-mandibular system. The possibility of developing a system of preventive measures non-biocidal action, mainly using probiotics, in particular autoprobiotics is considered.

Introduction. *Artificially modified habitats are created by humans when they learn the nature of things that lie outside the everyday conditions of existence. This primarily concerns the exploration of space, the ocean and the Earth's interior. To meet these challenges, artificial anthropo-ecosystems with modified habitat parameters are created. Under such altered conditions, the phylogenetically established coactant relationships of the human-micro-organism ecological system undergo changes. It takes the form of a syndrome of impaired colonization resistance [1].*

The aim *of the work was to characterise the three main barriers to infection that form in humans: defence group microflora, covering tissues and immunity, in conditions of isolation in hermetically sealed objects with altered environments in long-duration diving, in conditions simulating several factors of space flight (isolation and hypokinesia) and in spaceflight conditions.*