

DISCUSSION PAPERS, LECTURES, NEW TRENDS IN MEDICAL SCIENCE

EXPERIENCE OF USING A NEW MEDICAL SIMULATOR FOR CORRECTING SPASTICITY OF THE UPPER LIMB IN COMPLEX REHABILITATION OF CHILDREN WITH HEMIPLEGIC CEREBRAL PALSY

**Belogorova T.A.¹,
Mashanskaya A.V.^{1,2},
Vlasenko A.V.¹,
Mikhnovich V.I.¹,
Litvintseva O.M.¹,
Berdina O.N.¹,
Bugun O.V.¹,
Polyakov V.M.¹,
Rychkova L.V.¹**

¹ Scientific Centre for Family Health and Human Reproduction Problems (Timiryazev str., 16, Irkutsk 664003, Russian Federation)

² Irkutsk State Medical Academy of Postgraduate Education – Branch Campus of the Russian Medical Academy of Continuing Professional Education of the Ministry of Health of the Russian Federation (Yubileinii dstr., 100, Irkutsk 664049, Russian Federation)

Corresponding author:

Olga N. Berdina,
e-mail: goodnight_84@mail.ru

RESUME

Background. The hemiplegic form of cerebral palsy (CP) is the most prognostically promising in terms of the possibilities of correction and social adaptation of disabled children. However, the main limitation of successful rehabilitation is severe limb muscle spasticity, because so reducing muscle hypertonicity is a priority task in this disease.

The aim. To evaluate the effectiveness of improved method for correcting of upper limb spasticity in children with the hemiplegic form of CP.

Materials and methods. An open, non-randomized, prospective, comparative study was conducted involving two groups of patients with spastic hemiplegia with predominant damage to the upper limb, compared to the case-control type. The control group of children (n = 20) was treated using standard methods – drug therapy, exercise therapy, massage, physiotherapy; the main group (n = 20) was additionally prescribed exercises on the new medical simulator "Glove". The study participants in the groups were compared by gender, age and severity of motor impairment. The course in comprehensive rehabilitation lasted 10 days. The effectiveness of the improved method for correcting upper limb spasticity was assessed by studying the dynamics of motor function indices using scales for assessing muscle tone (modified Ashworth scale) and manual skills (Frenchai and ARAT tests, V.G. Bositykh and N.T. Pavlovskaya method).

Results. The additional inclusion of training using the new medical simulator for correcting upper limb spasticity "Glove" in the rehabilitation program for children with hemiplegic CP allowed achieving a significantly better treatment result with a significant decrease in muscle tonus, an increase in the volume and accuracy of movements, including in the section of small differentiated acts, with the elimination of the phenomenon of the «learned non-use» phenomenon.

Conclusions. The use of a new medical simulator in the complex therapy of children with spastic hemiplegia allows increasing its effectiveness relative to standard rehabilitation methods. However, the question of the long-term effect remains open and requires an assessment of longer-term use of the simulator in the interhospital period.

Keywords: cerebral palsy, hemiplegia, upper limb, spasticity, rehabilitation, medical simulators, functional electrical stimulation, children

Received: 16.09.2025
Accepted: 06.11.2025
Published: 26.11.2025

For citation: Belogorova T.A., Mashanskaya A.V., Vlasenko A.V., Mikhnovich V.I., Litvintseva O.M., Berdina O.N., Bugun O.V., Polyakov V.M., Rychkova L.V. Experience of using a new medical simulator for correcting spasticity of the upper limb in complex rehabilitation of children with hemiplegic cerebral palsy. *Acta biomedica scientifica*. 2025; 10(5): 12-23. doi: 10.29413/ABS.2025-10.5.2

ОПЫТ ПРИМЕНЕНИЯ НОВОГО МЕДИЦИНСКОГО ТРЕНАЖЕРА ДЛЯ КОРРЕКЦИИ СПАСТИЧНОСТИ ВЕРХНЕЙ КОНЕЧНОСТИ В КОМПЛЕКСНОЙ РЕАБИЛИТАЦИИ ДЕТЕЙ С ГЕМИПЛЕГИЧЕСКОЙ ФОРМОЙ ЦЕРЕБРАЛЬНОГО ПАРАЛИЧА

**Белогорова Т.А.¹,
Машанская А.В.^{1,2},
Власенко А.В.¹,
Михнович В.И.¹,
Литвинцева О.М.¹,
Бердина О.Н.¹,
Бугун О.В.¹,
Поляков В.М.¹,
Рычкова Л.В.¹**

¹ ФГБНУ «Научный центр проблем здоровья семьи и репродукции человека» (664003, г. Иркутск, ул. Тимирязева, 16, Россия)

² Российская медицинская академия непрерывного профессионального образования, Иркутская государственная медицинская академия последипломного образования – филиал ФГБОУ ДПО РМАНПО Минздрава России (664049, г. Иркутск, м-н Юбилейный, д. 100, Россия)

Автор, ответственный за переписку:
Бердина Ольга Николаевна,
e-mail: goodnight_84@mail.ru

РЕЗЮМЕ

Обоснование. Гемиплегическая форма детского церебрального паралича (ДЦП) является наиболее прогностически перспективной в отношении возможностей коррекции и социальной адаптации детей-инвалидов. Однако основным ограничением успешности реабилитации является выраженная спастичность мышц пораженной конечности, поэтому снижение мышечного гипертонуса является первоочередной задачей при данном заболевании.

Цель исследования. Оценить эффективность применения усовершенствованного способа коррекции спастичности верхних конечностей у детей с гемиплегической формой ДЦП.

Методы. Проведено открытое нерандомизированное проспективное сравнительное исследование с участием двух групп пациентов со спастической гемиплегией с преимущественным поражением рук, сопоставленных по типу случай-контроль. Контрольная группа детей ($n = 20$) была пролечена по стандартным методикам: медикаментозная терапия, лечебная физкультура, массаж, физиолечение; основной группе ($n = 20$) дополнительно были прописаны занятия на новом медицинском тренажере «Перчатка». Участники исследования в группах были сопоставлены по полу, возрасту и степени тяжести двигательных нарушений. Курс комплексной реабилитации составил 10 дней. Оценка эффективности усовершенствованного способа коррекции спастичности верхних конечностей проводилась за счет изучения динамики показателей двигательных функций по шкалам для оценки мышечного тонуса (модифицированная шкала Ашфорта) и мануальных навыков (тесты Френчай и ARAT, методика В.Г. Босых и Н.Т. Павловской).

Результаты. Дополнительное включение в программу реабилитации детей с гемиплегической формой ДЦП тренировок с помощью нового медицинского тренажера для коррекции спастичности рук «Перчатка» позволило достичь достоверно лучшего результата лечения со значимым снижением гипертонуса мышц, увеличением объема и точности движений, в том числе в разделе мелких дифференцированных актов, с устранением феномена «игнорирования» паретичной руки.

Заключение. Применение нового медицинского тренажера в комплексной терапии детей со спастической гемиплегией позволяет повысить ее эффективность относительно стандартных методик реабилитации. Однако вопрос о долгосрочности эффекта до сих пор остается открытым и требует более длительного применения тренажера в межстационарный период.

Ключевые слова: церебральный паралич, гемиплегия, верхняя конечность, спастичность, реабилитация, медицинские тренажеры, функциональная электростимуляция, дети

Для цитирования: Белогорова Т.А., Машанская А.В., Власенко А.В., Михнович В.И., Литвинцева О.М., Бердина О.Н., Бугун О.В., Поляков В.М., Рычкова Л.В. Опыт применения нового медицинского тренажера для коррекции спастичности верхней конечности в комплексной реабилитации детей с гемиплегической формой церебрального паралича. *Acta biomedica scientifica*. 2025; 10(5): 12-23. doi: 10.29413/ABS.2025-10.5.2

Статья поступила: 16.09.2025

Статья принята: 06.11.2025

Статья опубликована: 26.11.2025

INTRODUCTION

Cerebral palsy (CP) is a complex of non-hereditary, non-progressive disorders of the motor functions of maintaining posture and balance that arise as a result of damage to the central nervous system (CNS) in the ante-, intra-, or neonatal period, causing persistent limitation of activity, often combined with intellectual-mnemonic, speech, visual, and paroxysmal disorders [1]. The prevalence of this pathology as a whole, according to various sources, is 2.5-3 people per 1000 children per year. In the Russian Federation, this figure exceeds the prevalence in other countries and amounts to 4–5 cases per 1000 newborns [2]. The CP consequences significantly contribute to the increase in childhood disability rates due to neurological diseases. Moreover, the leading clinical CP manifestation, causing limitation of life activities and the need for outside assistance to perform everyday activities, is a syndrome of movement disorders [3, 4]. A common form of cerebral palsy, which ranks second in terms of incidence among the child population after classical diplegia (Little's paralysis), is spastic hemiplegia, which is clinically manifested by impaired movement function of the right or left limbs due to increased tone and decreased muscle strength when the opposite hemisphere of the brain is affected [5]. The leading symptom of this cerebral palsy form is spasticity, which develops as a result of damage to the central motor neurons and impairs the patients' quality of life. Such children require constant care and assistance from loved ones, long-term courses of expensive complex therapy, both in-patient and out-patient settings. Despite the fact that hemiplegic cerebral palsy has the most promising prognosis in terms of rehabilitation and social integration for children with disabilities, the main challenge to successful rehabilitation efforts is the pronounced muscle spasticity in the affected limb; therefore, reducing muscle tone is a priority for this condition [6, 7]. The most challenging aspect of rehabilitation for children with spastic hemiplegia is restoring motor function in the upper limb due to the paretic position of the hand and fingers, as well as the frequently occurring phenomenon of "ignoring" the paretic hand, also known as "learned non-use" [8, 9]. It should be noted that the hand is the most important part of the upper limb due to its ability to perform complex and varied motor acts, precisely coordinated by the central nervous system [10]. Restoring movement in a paired organ such as the upper limb is not enough; it is also necessary to identify and overcome the "learned non-use" phenomenon. Despite the high relevance of this problem in modern neurology and pediatrics, as well as the development of science and technology, there is currently no consensus on the rehabilitation of children with movement disorders, including spastic hemiplegia and upper limb dysfunction. This necessitates the priority and potential of additional scientific research in this area.

THE AIM OF THE STUDY

To evaluate the effectiveness of improved method for correcting upper limb spasticity in children with hemiplegic cerebral palsy.

MATERIALS AND METHODS

Study design: open, non-randomized, prospective, comparative study in parallel groups.

Following the initial examination of children, including an assessment of clinical and anamnestic data and neurological status, a clinical and rehabilitation diagnosis was made, short-term and long-term rehabilitation goals were determined, two groups of patients with hemiplegic cerebral palsy with predominant damage to the upper limbs were formed, compared according to the case-control type, and a rehabilitation plan was developed.

The study included 40 children aged 4 to 16 years: 20 (8 girls and 12 boys) formed the main group (MG) and 20 (7 girls and 13 boys) formed the control group (CG). Patients were matched by sex, age, clinical symptoms, and severity of motor impairments. Overall motor development was assessed and motor impairments were identified using the Gross Motor Function Classification System (GMFCS). Upper limb motor function was assessed using the Manual Ability Classification System (MACS) for children with cerebral palsy.

Eligibility criteria

Inclusion criteria:

- patients aged 4 to 16 years;
- hemiplegic cerebral palsy;
- moderate motor impairment (GMFCS II-III and MACS II-IV);
- preserved cognitive status;
- signed informed consent to participate in the study.

Exclusion criteria:

- consequences of severe traumatic brain injury and neuroinfections;
 - congenital brain malformations with severe neurological deficits;
 - low rehabilitation potential due to severe comorbidities;
 - patients/legal representatives who are not familiar with the aims and objectives of the study.
- #### *Exclusion criteria:*
- development or exacerbation of comorbidities, acute infectious diseases;
 - patient/legal representative's refusal to participate in the study at any stage.

Study design

Patients were recruited for the study groups and rehabilitation programs at the Department of Neurology and Department of Physiotherapy, Exercise Therapy, and Massage at the Clinic of the Scientific Center for Family Health and Human Reproduction problems

(Irkutsk) from January 2024 to July 2025, from patients hospitalized with a diagnosis of cerebral palsy, according to the inclusion/exclusion criteria.

Study duration

The study duration was limited to the time of patients' hospitalization in the neurology department for rehabilitation and was 10 days (with a weekend break). Motor performance was assessed on the day of hospitalization and discharge, taking into account the patient's baseline motor status and its dynamics after completing the comprehensive rehabilitation program.

Description of the medical intervention

In accordance with clinical guidelines and the study protocol, all patients in the MG and CG received ultrasound-guided injections of botulinum toxin (BTA) on the day of hospitalization [11-14].

From the second day of hospitalization, all patients underwent intensive comprehensive rehabilitation, including standard drug therapy and a range of physiotherapeutic procedures (exercise therapy, physiotherapy, massage, and reflexology). All training and procedures under the rehabilitation program began 1 hour after breakfast. Exercise therapy sessions, including those using a medical simulator, were conducted by a qualified physician-instructor and included a set of special exercises to prevent the development of contractures, hypotonia, and/or muscle atrophy, as well as the formation of correct motor patterns and stimulation of object-manipulative activity. In order to reduce the hypertonicity of the upper limb muscles, patients in both groups were provided with a set of relaxation exercises at the start and throughout each exercise therapy session (including the use of the "Glove" simulator), in the form of free swinging and shaking of the hand, clapping on a flat surface using a relaxed hand, and massaging the hand and fingers [15]. Physiotherapy was performed using segmental electropulse stimulation of the cervical spine with the Lymphavizine device (No. 10). Patients in the MG and CG received standard nootropic and metabolic medications at age-appropriate doses.

Patients in the MG were additionally underwent daily training using a new medical simulator "Glove" to further correct upper limb spasticity (the training course lasted 10 days and included five sessions per week, lasting 30–40 minutes each, depending on the patient's age and ability to tolerate the physical activity) (Fig. 1).

The "Glove" rehabilitation simulator (developed in collaboration with Prototype LLC (Samara, Russia)) is a device for kinesiotherapy for upper limb spasticity. It improves the effectiveness of physical rehabilitation methods (specifically, kinesiotherapy) for patients with cerebral palsy, both in out-patient settings (at clinics, rehabilitation departments, sanatoriums, etc.) and at home, where patients often find the most comfort between hospitalizations. This portable medical device allows children to develop and strengthen

skills in using their paretic hand, particularly the wrist and fingers, in a playful manner, and to reduce the severity of the common phenomenon known as "learned non-use" creating a positive emotional environment and additional motivation for the rehabilitation process. Built-in median nerve electrical stimulation, which activates damaged nerve pathways and improves muscle impulse transmission, helps restore control over paralyzed limbs by enhancing the activity of surviving neural connections and helps prevent muscle atrophy and secondary biomechanical complications [16].

Study outcomes

The primary outcome of the study was to determine whether there were differences between the MG and CG in terms of motor skills, muscle tone, and upper limb muscle strength at the time of hospital admission and after completion of an intensive short-term rehabilitation program.

Secondary outcome: not included.

Subgroup analysis: not performed.

Methods of recording outcomes

The effectiveness of the improved method for correcting upper limb spasticity was assessed based on the dynamics of muscle tone indicators, as well as the level of motor activity and motor skills of the upper limb, using the following methods and scales:

1) Modified Ashworth Scale. This scale was validated in the Russian Federation in 2020 [17]. The test results are scored as follows:

0 points – no increase in muscle tone;

1 point – slight increase in muscle tone and minimal muscle tension at the end of the movement pattern when flexing or extending the affected limb;

2 points – mild increase in muscle tone during grasping, accompanied by minimal resistance;

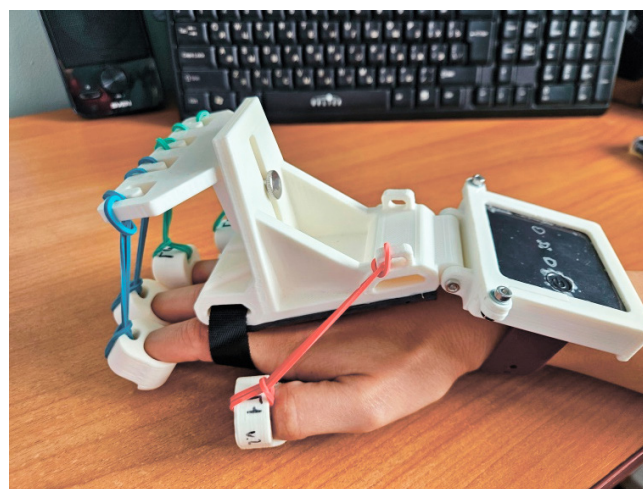


FIG. 1. Medical simulator "Glove" for correcting of upper limb spasticity

3 points – more pronounced increase in muscle tone across most of the range of movement, with limited passive motor activity;

4 points – significant muscle tension with marked difficulty in passive movement;

5 points – flexion or extension contracture of the limbs.

2) The Frenchay Arm Test for studying the gestural-communicative function of the upper limb (non-verbal communication function) [8]. The method includes 5 tasks: fixing an object (ruler) using the hand, grasping cylindrical objects of various diameters, using a pinch grip, and touching the top of the head.

3) A modified ARAT (Action Research Arm Test) test for assessing the motor activity of the affected limb [18]. This international scale, which provides a detailed assessment of the motor function of the hand and fingers, allows for the evaluation of various types of grip, as well as large movements of the joints, consists of 19 assessed items (tasks), which are divided into four subtests (subtest 1 – ball grip; subtest 2 – cylindrical grip, squeezing an object; subtest 3 – pinch grip; subtest 4 – large movements of the hand – extension and flexion in the elbow and shoulder joints). A standard set of items is provided for performing the testing procedure. The ARAT test has high sensitivity even with minor changes in the pattern of movements of the upper limb, especially in patients with spastic syndromes.

4) The method of V.G. Bosykh and N.T. Pavlovskaya [19] is intended for additional assessment of manual functions in children with different forms of cerebral palsy during their daily activities. During examination of the motor functions of the upper limb, the range of motion in the joints, the position of the hands during walking and performing manual skills, the presence and degree of spasticity, the ability to voluntarily hold and release an object, the development of the main types of grips and their quality, the ability to perform manipulations with objects, their quality and speed of execution, the ability to perform isolated movements of the fingers, and the characteristics of graphic skills are determined. Each hand is assessed separately on a five-point scale.

Statistical analysis

The sample size was not calculated in advance. Statistical processing of the study results was performed using Statistica for Windows version 10.0 (StatSoft, USA). Continuous data were presented as the median (Me) with upper and lower quartiles [25th and 75th percentiles] due to the small sample size in each group (preliminary testing of groups for normal distribution was not performed); qualitative characteristics were presented as absolute values and percentages of observations. Comparability of clinical and demographic parameters between the MG and CG was assessed using the Mann–Whitney U-test. When comparing groups based on qualitative characteristics, the χ^2 test with Yates' correction was used (if the number of observations in any cell was <10). In cases of a small number of observations (up to 5), Fisher's

exact test was used. Treatment effectiveness was assessed based on changes in manual function across groups using the Wilcoxon signed-rank test (W) for dependent samples. All differences were considered significant at $p < 0.05$.

Compliance with ethical principles and ethical review of the study

The ethical principles outlined in the World Medical Association Declaration of Helsinki (1964), as amended in 2024 (amended at the 75th General Assembly of the World Medical Association, Helsinki), were observed in the study with patients. All study procedures were conducted only with the informed voluntary consent (IVC) of patients (upon reaching the age of 15 and being recognized as competent) and their legal representatives, signed on the day of hospitalization. The study protocol and accompanying documents (information sheet and IVC) were pre-approved by the local Biomedical Ethics Committee of the Scientific Centre for Family Health and Human Reproduction Problems (Protocol No. 5 dated June 5, 2023).

RESULTS

The motor sphere parameters, specifically muscle tone, motor functions and skills of the affected upper limb, were analyzed in 40 patients with hemiplegic cerebral palsy, assessed before and after an intensive short-term rehabilitation course according to the protocol of this study.

Characteristics of the comparison groups

Before the study began, the MG and CG patients with cerebral palsy were similar in age, sex, severity of motor impairments according to the GMFCS and MACS, and the nature of perinatal CNS pathology. Distribution of patients by the side of the affected limb revealed a predominance of right-hand paresis in the CG (Table 1).

Main results of the study

When comparing the results of the modified Ashworth scale before treatment, no statistically significant differences were found between the MG and CG. Upper limb muscle spasticity was expressed equally in all patients (Me 3 points [25–75%: 2–3] in the MG versus Me 3 points [25–75%: 2–4] in the CG, $p = 0.175$). After a short-term course of intensive comprehensive rehabilitation, patients in the MG achieved significant positive dynamics in these indicators, which was not observed in the CG (Me 2 points [25–75%: 1–2], and Me 3 points [25–75%: 2–4], respectively, $p_w = 0.015$ and $p_w = 0.875$).

A comparative analysis of the efficacy of the comprehensive rehabilitation programs for two groups of patients with spastic hemiplegia is presented in Table 2 and Figure 2.

An analysis of the dynamic changes in motor function after a short-term course of intensive rehabilitation for patients with cerebral palsy at a neurological

hospital revealed that improved motor performance and the development of new motor skills was observed in patients from both groups, accompanied by an increased frequency in the use of alternative movement patterns and greater precision in performing manipulative tasks. However, motivation for bi-manual movement in the CG was only observed upon prompting and was very limited. A sustained increase in motivation was observed in only 10 % of children from the CG, while this indicator in the MG reached

55 % ($p = 0.007$), but mainly with mild to moderate severity of movement disorders (GMFCS and MACS levels II-III). A similar distribution of patients in the MG and CG was observed with respect to a reduction in the incidence of the phenomenon of "ignoring" the paretic hand (10 % and 60 %, respectively, $p = 0.003$). However, the efficiency of movements improved only in some patients in the MG, but not in the control. Overall, it should be noted that the dynamics of motor activity indicators in the affected upper limb during

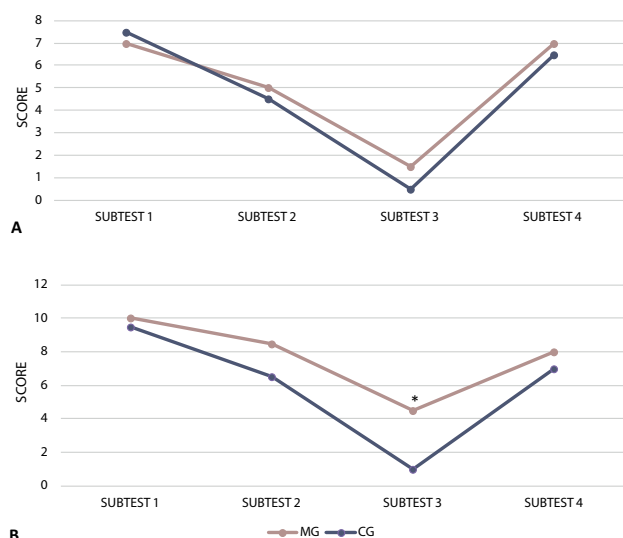
TABLE 1
INITIAL CLINICAL AND DEMOGRAPHIC CHARACTERISTICS OF PATIENTS

Indicator	MG (n = 20)	CG (n = 20)	p-level
Age, years	10[7-12]	9.5[7-12.5]	0.989
Sex:			
girls	8(40)	7(35)	1.000
boys	12(60)	13(65)	1.000
Lateralization of the upper limb lesion:			
right hand	10(50)	15(75)	0.191
left hand	10(50)	5(25)	0.191
<i>Severity of movement disorders</i>			
GMFCS:			
I	-	-	
II	15(75)	14(70)	1.000
III	5(25)	6(30)	1.000
IV	-	-	
V	-	-	
MACS:			
I	-	-	
II	4(20)	5(25)	1.000
III	12(60)	10(50)	0.525
IV	4(20)	5(25)	1.000
V	-	-	
<i>Types of perinatal organic brain damage</i>			
Porencephalic and other cysts, hypoplasia of the corpus callosum and other parts of the brain	7(25)	6(30)	1.000
Periventricular leukomalacia	2(10)	2(10)	0.598
Adreno-, leuko-dystrophy, cystic gliosis changes	3(15)	3(15)	0.658
Hydrocephalus, ventriculomegaly	5(25)	5(25)	0.715
ACVA	2(10)	2(10)	0.598
Hypoxic/toxic-ischemic brain injury	2(10)	3(15)	1.000
Combination of brain pathologies	5(25)	5(25)	0.715

Note. The data are presented as Me [25%–75%] and abs. (%). ACVA – acute cerebrovascular accident; GMFCS – Gross Motor Function Classification System; MACS – Manual Ability Classification System. p – level of statistical significance of differences in groups, taking into account the criteria: 1 – Pearson χ^2 with Yates' correction and 2 – Fisher's exact test.

comprehensive rehabilitation were more intense with the additional use of the new “Glove” device in the exercise therapy program, due to a statistically significant reduction in spasticity in the arm muscles, particularly in the hands and fingers, including their distal regions. This significantly improved manual activity (including the gestural and communicative

function of the upper limb according to The Frenchay Arm Test) in terms of not only “large”, “undifferentiated”, and “immature” movements, primarily due to an increase in range of motion in large joints and the ability to grasp, hold, and release a large object (typical of patients in the control group), but also “fine” motor skills, including improved quality and speed of cylindrical and pinch grasps (Fig. 2). Most patients with spastic hemiplegia who underwent intensive rehabilitation using an improved method for correcting upper limb spasticity also demonstrated significant improvements in their ability to perform isolated finger movements and in their graphic skills using the additional method of V.G. Bosykh and N.T. Pavlovskaya.



* – $p < 0,05$ – statistically significant differences between groups according to the U-test.

FIG. 2. Indicators of ARAT's subtests in the main and control groups. A – pre-treatment; B – post-treatment

DISCUSSION

Summary of the main study findings

The addition of the new “Glove” medical simulator for correcting hand spasticity in the short-term intensive rehabilitation program for children with hemiplegic cerebral palsy resulted in significantly improved treatment outcomes in the neurology department, with a significant reduction in upper limb muscle tone, an increase in the range and precision of movement, including fine-grained movements, and the elimination of the phenomenon of “ignoring” the paretic hand.

Discussion of the main study findings

To date, numerous programs, methods, and devices have been developed for the rehabilitation of motor functions in cerebral palsy, most of which have established a strong reputation in the medical and patient (parent) communities due to their high effectiveness and reduced socioeconomic burden on families and the state. However, the therapeutic effect of many of these is primarily aimed at developing

TABLE 2
ANALYSIS OF DIFFERENCES IN THE SCALES FOR ASSESSING MANUAL SKILLS IN PATIENTS OF THE MAIN AND CONTROL GROUPS BEFORE AND AFTER TREATMENT

Indicator	Period	MG (n = 20)	CG (n = 20)	p_u	p_w MG/ p_w CG
The Frenchay Arm Test, score	initially	3 [2-6.5]	4 [2-6.5]	0.913	0.036/
	after treatment	6 [5-8]	5 [3-8]	0.061	0.745
ARAT test, total score	initially	23 [7.5-27.5]	21.5 [8-34.5]	0.924	0.017/
	after treatment	35.5 [17.5-53.5]	24.5 [13-39.5]	0.116	0.528
Method of V.G. Bosykh and N.T. Pavlovskaya, score	initially	21 [19.5-28]	25.5 [21-31.5]	0.171	0.027/
	after treatment	31.5 [25.5-35]	28.5 [24-32.5]	0.328	0.354

Note. The data are presented as Me [25%–75%]. ARAT – Action Research Arm Test, a test of hand motor activity. p_u is the level of statistical significance of differences between the MG and CG according to the Mann–Whitney criterion; p_w is the level of statistical significance of differences in groups according to the Wilcoxon T-criterion.

the muscles of the lower torso and legs and developing a physiological gait pattern [4, 20-22]. At the same time, the theoretical and practical aspects of rehabilitation of children with upper limb impairments remain a pressing and challenging task in pediatric science and clinical neurology. It should be noted that the human hand plays a vital role at all stages of ontogenesis in the development of verticalization and balance, which, in turn, allows the child to free the upper limbs to perform complex manipulations, develop and refine fine differentiated motor acts (including drawing and writing), and self-care skills [15]. Functionally, the hand is the most important part of the upper limb [23]. For children with cerebral palsy, pathognomonic symptoms include pronation of the forearm, flexion contracture of the distal upper limb, and inability to abduct the thumb, which hinders or eliminates manipulation of objects and, in turn, complicates the rehabilitation process and reduces its effectiveness [24]. In severe paresis and organic brain damage, these motor impairments are accompanied by the phenomenon of "ignoring" the paretic hand, as demonstrated in our study. Given the high functional significance of the upper limb in everyday activities, early and complete restoration of its motor activity is a pressing task.

Our study is not a pioneer in this area, including among domestic developments of rehabilitation simulators for restoring upper limb function. The reviews by E.A. Biryukov et al. (2022), Chen Y.P. et al. (2016), and Cardone D. et al. (2025) emphasized the importance of modern rehabilitation technologies for improving upper limb function [25-27]. However, the reviewed studies on this topic, in patients with cerebral palsy, primarily demonstrate the use of robotic simulators and devices equipped with biofeedback or a computer-based neurointerface, where the development of correct upper limb motor patterns is achieved primarily through a passive training and the acquisition of adaptive sensory-motor experience by the child. Our development does not include robotic elements; the child must apply voluntary effort to perform active actions with the upper limb. However, the game-based nature of the training helped to increase motivation for training and its effectiveness, similar to previously created rehabilitation devices. It is worth highlighting four studies in which patients, as in our study, suffered from the hemiplegic form of cerebral palsy and had similar severity of motor impairments according to the GMFCS and MACS [9, 28-30], in one of which [29] the frequency and exposure of intervention using the simulator corresponded to that stated by us (10 days, 30 minutes per day). The authors obtained similar results regarding the improvement of fine differentiated movements of the hand and fingers, the speed and accuracy of manipulations, and the emergence of bimanual activity, that is, a decrease in the frequency of the phenomenon of "learned non-use", as demonstrated in this study

in children with spastic hemiplegia. The importance of using functional electrical stimulation (provided for in the developed device) in combination with kinesiotherapy is also confirmed in the study of Kim T-W. et al. (2016) to correct spasticity and stimulate the wrist extensor muscles, and as a result, improve wrist extension and fine motor skills of the hand and fingers [30].

The primary objective of neurorehabilitation for patients with paralytic syndromes is to restore motor function and prevent the development of secondary biomechanical complications. Unfortunately, severe muscle spasticity in cerebral palsy impairs the quality of life of patients and their families, hinders the development of complex motor skills, and complicates rehabilitation measures. There is no single, universally accepted method for correcting it, making scientific research and innovation in this field a priority and a justified approach. This research direction is outlined in the study.

Study limitations

The main limitation of our study was the small sample size of patients with spastic hemiplegia and the small number of participants in the comparison groups, which precludes the generalization of our results to the general population of patients with this form of cerebral palsy. It should be noted that our results are consistent with the hypothesis that comprehensive rehabilitation programs aimed at restoring motor function in cerebral palsy are more effective in children with mild to moderate motor impairments. However, this study's limitation prevented us from analyzing the efficacy of the improved method for correcting upper limb muscle spasticity among patients of all GMFCS functional levels (I-V). Furthermore, in order to achieve the desired treatment outcomes in only a selected group of patients, it is necessary to incorporate specific features into the developed simulator to enhance the rehabilitation process, increase motivation and adherence to treatment, and programmatically analyze the obtained data, such as biofeedback and SOI. Limitations of this study also include the lack of long-term follow-up of the patients treated, which would allow for assessment of the long-term effectiveness of the rehabilitation program. Further research is needed to evaluate the effectiveness of the new medical simulator "Glove", the development and clinical application of updated models, taking into account the identified limitations of this study.

CONCLUSION

The effectiveness of the chosen comprehensive rehabilitation program for children with cerebral palsy determines the subsequent prognosis of the disease, with either regression of motor function impairment or transformation into a permanent motor defect.

To develop the optimal combination of rehabilitation methods and determine the parameters for restorative treatment procedures, it is necessary to analyze the comparative efficacy and evaluate the immediate and long-term results of treatment and rehabilitation methods and devices. In our study, the use of an improved method for correcting upper limb muscle spasticity in patients with hemiplegia demonstrated positive results in terms of reducing abnormal muscle tone in the upper limb, increasing the range and precision of movement, including small and differentiated movements, and eliminating the phenomenon of “ignoring” the paretic arm. Thus, the use of a new medical simulator in the comprehensive treatment of children with hemiparetic cerebral palsy allows for increased efficacy compared to standard rehabilitation methods. However, the long-term efficacy of such training remains unclear and requires evaluation of longer-term simulator usage for self-rehabilitation during the post-hospital period. In this regard, the development of treatment and rehabilitation programs based on new technologies for the non-pharmacological correction of motor dysfunction in children with paralytic syndromes and cerebral palsy, ensuring the continuity of rehabilitation processes through the seamless transition between inpatient and outpatient stages and their rapid implementation into practical health care, are relevant areas of innovative research and development in modern neuropsychiatry.

Funding

The study was conducted as part of the exploratory scientific research topic “Applied aspects of rehabilitation for children with neurological disorders” which was supported by a state assignment for the Scientific Centre for Family Health and Human Reproduction Problems.

Conflicts of interest

No potential conflict of interest relevant to this article reported.

Acknowledgments

The authors of the article would like to express their gratitude to Drs. N.Y. Dutova and T.V. Taskaeva, from the Neurology Department at the Clinic of the Scientific Centre for Family Health and Human Reproduction Problems, for their contribution to the collection of clinical data. Additionally, the authors would like to thank the medical staff at the Physiotherapy, Physical Therapy, and Massage Department of the same clinic for their assistance with conducting research-related procedures as part of the study.

REFERENCES

1. Cerebral palsy (CP). Clinical guidelines. *Vestnik vosstanovitel'noj mediciny*. 2017; 3(79): 91-114. (In Russ.). [Детский церебральный паралич (ДЦП). Клинические рекомендации. *Вестник восстановительной медицины*. 2017; 3(79): 91-114].
2. Namazova-Baranova LS, Deev IA, Kobyakova OS, Kulikova KV, Kulikov ES, Zhelev VA, et al. Features of somatic pathology in children with low, very low and extremely low birth weight at different ages of life (review of the world literature). *Byulleten' sibirskoj mediciny*. 2016; 15(4): 140-149. (In Russ.). [Намазова-Баранова Л.С., Деев И.А., Кобякова О.С., Куликова К.В., Куликов Е.С., Желев В.А. и др. Особенности соматической патологии у детей с низкой, очень низкой и экстремально низкой массой тела при рождении в различные возрастные периоды жизни. *Бюллетень сибирской медицины*. 2016; 15(4): 140-149]. doi: 10.20538/1682-0363-2016-4-140-149
3. Deineko VV, Krysyuk OB, Safonov LV, Shurygin SN. Modern opportunities and prognosis of physical rehabilitation of children with cerebral palsy. *Zhurnal nevrologii i psixiatrii im. S.S. Korsakova*. 2020; 120(6): 88-91. (In Russ.). [Дейнеко В.В., Крысюк О.Б., Сафонов Л.В., Шурыгин С.Н. Современные возможности и прогноз физической реабилитации детей с церебральным параличом. *Журнал неврологии и психиатрии им. С.С. Корсакова*. 2020; 120(6): 88-91]. doi: 10.17116/jnevro202012006188
4. Bugun OV, Mashanskaya AV, Atalyan AV, Mihnovich VI, Belogorova TA, Vlasenko AV, et al. Comprehensive rehabilitation of patients with movement disorders with spastic forms of cerebral palsy. *Acta Biomedica Scientifica*. 2021; 6(6-2): 82-91. (In Russ.). [Бугун О.В., Машанская А.В., Аталян А.В., Михнович В.И., Белогорова Т.А., Власенко А.В. и др. Комплексная реабилитация пациентов с двигательными нарушениями при спастических формах ДЦП. *Acta Biomedica Scientifica*. 2021; 6(6-2): 82-91]. doi: 10.29413/ABS.2021-6.6-2.9
5. Semenova EV, Klochkova EV, Korshikova-Morozova AE, Truhachyova AV, Zablockis EYu, et al. *Rehabilitation of children with cerebral palsy: review of modern approaches to help rehabilitation centers*. М.: Lepta Книга, 2018. (In Russ.). [Семенова Е.В., Клочкова Е.В., Коршикова-Морозова А.Е., Трухачёва А.В., Заблочкис Е.Ю. *Реабилитация детей с ДЦП: обзор современных подходов в помощь реабилитационным центрам*. М.: Лепта Книга, 2018].
6. Lupandina-Bolotova GS, Klochkova OA, Zherdev KV, Ignatov DA, Namazova-Baranova LS, Polyakov SD, et al. Optimization of early physical rehabilitation of patients with spastic infantile cerebral palsies. *Pediatricheskaya farmakologiya*. 2014; 11(5): 104-108. (In Russ.). [Лупандина-Болотова Г.С., Клочкова О.А., Жердев К.В., Игнатов Д.А., Намазова-Баранова Л.С., Поляков С.Д. и др. Оптимизация ранней физической реабилитации пациентов со спастическими формами детского церебрального паралича. *Педиатрическая фармакология*. 2014; 11(5): 104-108]. doi: 10.15690/pf.v11i5.1173
7. Berdina O, Mihnovich V, Belogorova T, Vlasenko A, Bolshakova S, Bugun O. Rehabilitation of children

- with spastic forms of cerebral palsy (new technologies). *Vrach.* 2019; 30(9): 52-56. (In Russ.). [Бердина О., Михнович В., Белогорова Т., Власенко А., Большакова С., Бугун О. и др. Реабилитация детей со спастическими формами ДЦП (новые технологии). *Врач.* 2019; 30(9): 52-56]. doi: 10.29296/25877305-2019-09-10
8. Kovalenko AP, Kamaeva OV, Poleshchuk YuR, Kovlen DV. Scales and tests in the rehabilitation and treatment of patients with spasticity of the upper limbs. *Zhurnal nevrologii i psikiatrii im. S.S. Korsakova.* 2020; 120(4): 107-114. (In Russ.). [Коваленко А.П., Камеева О.В., Полещук Ю.Р., Ковлен Д.В. Шкалы и тесты в реабилитации и лечении пациентов со спастичностью верхней конечности. *Журнал неврологии и психиатрии им. С.С. Корсакова.* 2020; 4: 107-114]. doi: 10.17116/jnevro2020120041107
9. Lunina NV, Skoryukova KS. Application of game biocontrolled mechanotherapy in the restoration of motor functions of the upper limb in hemiparetic form of childhood cerebral palsy. *Sovremennye voprosy biomeditsiny.* 2023; 7(1). (In Russ.). [Лунина Н.В., Скорюкова К.С. Применение игровой биоуправляемой механотерапии в восстановлении моторных функций верхней конечности при гемипаретической форме детского церебрального паралича. *Современные вопросы биомедицины.* 2023; 7(1)]. doi: 10.51871/2588-0500_2023_07_01_19
10. Lysov PK. Anatomy. M.: *Fizicheskaya kul'tura i sport*, 2010. (In Russ.). [Лысов П.К. Анатомия. М.: *Физическая культура и спорт*, 2010].
11. Berdina ON, Mihnovich VI, Belogorova TA, Bolshakova SE, Rychkova LV. Use of muscle relaxants in complex rehabilitation of children with spastic-dyskinetic forms of cerebral palsy. *Farmateka.* 2017; 11: 63-66. (In Russ.). [Бердина О.Н., Михнович В.И., Белогорова Т.А., Большакова С.Е., Рычкова Л.В. Применение миорелаксантов в комплексной реабилитации детей со спастико-дискинетическими формами детского церебрального паралича. *Фарматека.* 2017; 11: 63-66]. doi: 10.18565/pharmateca.2018.s4.54-57
12. Rychkova L, Mikhnovich V, Belogorova T, Vlasenko A, Dutova N, Taskaeva T. Rehabilitation of children with spastic cerebral palsy after botulinum toxin therapy. *Arch Dis Childh.* 2017; 102(S2): A149-A150. doi: 10.1136/archdischild-2017-313273.388
13. Kurenkov AL, Klochkova OA, Zmanovskaya VA, Falkovskij IV, Kenis VM, Vladykina LN, et al. Updated and revised Russian consensus on the use of multilevel injections of abobotulinumtoxin A in children. *Nevrologiya, nejropsihiatriya, psichosomatika.* 2024; 16(6): 125-133. (In Russ.). [Куренков А.Л., Клочкова О.А., Змановская В.А., Фальковский И.В., Кенис В.М., Владыкина Л.Н. и др. Обновленный и дополненный российский консенсус по применению многоуровневых инъекций абоботулинтокси А у детей. *Неврология, нейропсихиатрия, психосоматика.* 2024; 16(6): 125-133]. doi: 10.17116/jnevro2016116111121-130
14. Mashanskaya AV, Bugun OV, Atalyan AV, Mihnovich VI, Belogorova TA, Vlasenko AV, et al. Experience of using botulinum therapy and "kinesioplatform-swing" in the program of medical rehabilitation of children. *Vestnik fizioterapii i kurortologii.* 2022; 28(1): 91. (In Russ.). [Машанская А.В., Бугун О.В., Аталян А.В., Михнович В.И., Белогорова Т.А., Власенко А.В. и др. Опыт применения ботулинотерапии и кинезиоплатформы-качелей в программе медицинской реабилитации детей. *Вестник физиотерапии и курортологии.* 2022; 28(1): 91].
15. Legkaya EF, Khodasevich LS, Polyakova AV. Exercise therapy for development of in-hand manipulation skills in patients with infantile cerebral palsy. *Meditinskaya sestra.* 2018; 2(20): 32-38. (In Russ.). [Легкая Е.Ф., Ходасевич Л.С., Полякова А.В. Лечебная физкультура для развития манипулятивной деятельности рук у больных детским церебральным параличом. *Медицинская сестра.* 2018; 2(20): 32-38]. doi: 10.29296/25879979-2018-02-06
16. Berger AB, Konchugova TV. Transcutaneous electrical neurostimulation at the second stage of medical rehabilitation in ischemic stroke: a controlled randomized study. *Vestnik vosstanovitel'noj mediciny.* 2025; 24(3): 140-146. (In Russ.). [Бергер А.Б., Кончугова Т.В. Применение чрескожной электронейростимуляции на II этапе медицинской реабилитации при ишемическом инсульте: контролируемое рандомизированное исследование. *Вестник восстановительной медицины.* 2025; 24(3): 140-146]. doi: 10.38025/2078-1962-2025-24-3-140-146
17. Baranov AA, Namazova-Baranova LS, Albitskii VYu, Terletskaia RN, Antonova EV. *The condition and problems of adolescents' health in Russia.* M.: ООО Izd-vo "Pediater", 2020. (In Russ.). [Баранов А.А., Альбицкий В.Ю., Намазова-Баранова Л.С., Терлецкая Р.Н. *Состояние здоровья детей в современной России*; 2-е изд., доп. М.: ООО Изд-во «Педиатр», 2020.].
18. Bulekbaeva ShA, Lisovskij EV, Rizvanova AR, Daribaev ZhR. *Diagnostic scales and tests in neurorehabilitation: a guide for doctors.* Astana: АО «Respublikanskij detskij reabilitacionnyj centr», 2015. (In Russ.). [Булекбаева Ш.А., Лисовский Е.В., Ризванова А.Р., Дарибаев Ж.Р. *Диагностические шкалы и тесты в нейрореабилитации: руководство для врачей.* Астана: АО «Республиканский детский реабилитационный центр», 2015].
19. Bosyh VG, Pavlovskaya NT. Assessment of the severity of movement disorders in cerebral palsy in the form of spastic diplegia. *Special'naya psichologiya.* 2005; 1(3): 21-27. (In Russ.). [Босых В.Г., Павловская Н.Т. Оценка тяжести двигательных нарушений при ДЦП в форме спастической диплегии. *Специальная психология.* 2005; 1(3): 21-27].
20. Lobzin YuV, Ivanova MV, Skripchenko NV, Pulman NF, Vojtenkov VB, Najdin EYu. Experience of using robotic mechanotherapy in rehabilitation of children with motor disorders of various genesis. *Medicina ekstremal'nyh situacij.* 2015; 1: 22-26. (In Russ.). [Лобзин Ю.В., Иванова М.В., Скрипченко Н.В., Пульман Н.Ф., Войтенков В.Б., Найдин Е.Ю. Опыт

применения роботизированной механотерапии в реабилитации детей с двигательными нарушениями различного генеза. *Медицина экстремальных ситуаций*. 2015; 1: 22–26].

21. Mosina MO, Batysheva TT, Tikhonov SV, Selivanova EA. Exoskeletons in comprehensive rehabilitation of children with walking disorders. *Detskaya i подростковая реабилитация*. 2022; 1(46): 27–38. (In Russ.). [Мосина М.О., Батышева Т.Т., Тихонов С.В., Селиванова Е.А. Экзоскелеты в комплексной реабилитации детей с нарушением функции ходьбы. *Детская и подростковая реабилитация*. 2022; 1(46): 27–38].

22. Wang Y, Zhang P, Li C. Systematic review and network meta-analysis of robot-assisted gait training on lower limb function in patients with cerebral palsy. *Neurol Sci*. 2023; 44(11): 3863–3875. doi: 10.1007/s10072-023-06964-w

23. Volovec SA, Badalov NG, Borodulina IV, Yakovlev MYu. Efficiency of using a hardware complex with biological feedback in the rehabilitation of children with impaired upper limb function. *Voprosy kurortologii, fizioterapii i lechebnoj fizicheskoj kultury*. 2022; 99(5): 37–47. (In Russ.). [Воловец С.А., Бадалов Н.Г., Бородулина И.В., Яковлев М.Ю. Эффективность применения аппаратного комплекса с биологически обратной связью в реабилитации детей с нарушением функции верхних конечностей. *Вопросы курортологии, физиотерапии и лечебной физической культуры*. 2022; 99(5): 37–47]. doi: 10.17116/kurort20229905137

24. Badalyan LO, Zhurba LT, Timonina OV. *Cerebral palsy in children: CP, exercise therapy*. Neurology. М.: Книга по Требованию, 2013. (In Russ.). [Бадалян Л.О., Журба Л.Т., Тимонина О.В. *Детские церебральные параличи: ДЦП, ЛФК*. Неврология. М.: Книга по Требованию, 2013].

25. Biryukov EA, Yastrebtsseva IP. The importance of modern robotic rehabilitation technologies for improving upper limb function. *Doktor. Ru*. 2022; 21(8): 39–43. (In Russ.). [Бирюков Е.А., Ястребцева И.П. Значение современных роботизированных реабилитационных технологий для улучшения функции верхней конечности. *Доктор.Ру*. 2022; 21(8): 39–43]. doi: 10.31550/1727-2378-2022-21-8-39-43

26. Cardone D, Perpetuini D, Di Nicola M, Merla A, Morone G, Ciancarelli I, et al. Robot-assisted upper limb therapy for personalized rehabilitation in children with cerebral palsy: a systematic review. *Front. Neurol*. 2025; 15: 1499249. doi: 10.3389/fneur.2024.1499249

27. Chen YP, Howard AM. Effects of robotic therapy on upper-extremity function in children with cerebral palsy: a systematic review. *Dev Neurorehabil*. 2016; 19(1): 64–71. doi: 10.3109/17518423.2014.899648

28. El-Shamy SM. Efficacy of Armeo® robotic therapy versus conventional therapy on upper limb function in children with hemiplegic cerebral palsy. *Am J Phys Med Rehabil*. 2018; 97(3): 164–169. doi: 10.1097/PHM.0000000000000852

29. Roberts H, Shierk A, Clegg NJ, Baldwin D, Smith L, Yeatts P, et al. Constraint induced movement therapy camp for children with hemiplegic cerebral palsy augmented by use of an exoskeleton to play games in virtual reality. *Phys Occup Ther Pediatr*. 2020; 41: 150–65. doi: 10.1080/01942638.2020.1812790

30. Kim T-W, Lee B-H. Clinical usefulness of brain-computer interface-controlled functional electrical stimulation for improving brain activity in children with spastic cerebral palsy: a pilot randomized controlled trial. *J Phys Ther Sci*. 2016; 28: 2491–2494. doi: 10.1589/jpts.28.2491

Information about the authors:

Tatiana A. Belogorova – Cand. Sc. (Med.), Head of the department of neurology of Clinic of Scientific Centre for Family Health and Human Reproduction Problems; e-mail: belogorova.tat@mail.ru, <https://orcid.org/0000-0002-8982-9282>

Alexandra V. Mashanskaya – Cand. Sc. (Med.), associate professor at the department of physical medicine and rehabilitation, Irkutsk State Medical Academy of Postgraduate Education – Branch Campus of the Russian Medical Academy of Continuing Professional Education; Reflexologist at the department of physiotherapy, physical therapy and massage of Clinic of Scientific Centre for Family Health and Human Reproduction Problems; e-mail: ale-mashanskaya@yandex.ru, <https://orcid.org/0000-0003-1792-6822>

Anastasia V. Vlasenko – Cand. Sc. (Med.), head of the department of physical therapy and massage, Scientific Centre for Family Health and Human Reproduction Problems; e-mail: clin.fizio@yandex.ru, <https://orcid.org/0000-0001-7083-5474>

Vanda I. Mikhnovich – Cand. Sc. (Med.), neurologist at the department of neurology, Scientific Centre for Family Health and Human Reproduction Problems; e-mail: mihvini@irk.ru, <https://orcid.org/0000-0001-8421-7028>

Olga M. Litvintseva – physician of the exercise and occupation therapy at the Clinic, Scientific Center for Family Health and Human Reproduction Problems; e-mail: litvintseva-o@mail.ru

Olga N. Berdina – Dr. Sc. (Med.), leading researcher of the laboratory of somnology and neurophysiology, Scientific Centre for Family Health and Human Reproduction Problems; e-mail: goodnight_84@mail.ru, <https://orcid.org/0000-0003-0930-6543>

Vladimir M. Polyakov – Dr. Sc. (Biol.), Leading Research Officer at the Laboratory of Psychoneurosomatic Children's Pathology of Scientific Center for Family Health and Human Reproduction Problems; e-mail: vmpolyakov@mail.ru, <https://orcid.org/0000-0001-6243-9391>

Olga V. Bugun – Dr. Sc. (Med.), chief physician of the Clinic, Deputy Director for clinical work, Scientific Centre for Family Health and Human Reproduction Problems; e-mail: clinica_zam1@inbox.ru, <https://orcid.org/0000-0002-2162-3683>

Lyubov V. Rychkova – Dr. Sc. (Med.), corresponding member of the RAS, Professor, Director, Scientific Centre for Family Health and Human Reproduction Problems;
e-mail: iphrr@sbamsr.irk.ru, <https://orcid.org/0000-0002-0117-2563>