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Research Article

Efficiency of Locomotor Therapy Using the Reduced Gravity Krisaf Device in Children with Cerebral Palsy

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Abstract

Cerebral palsy (CP) is a group of non-progressive diseases that occur during pregnancy, intranatal, and postnatal periods and are manifested by varying degrees of nervous system disorders. The frequency of CP incidence, according to various authors, ranges from 1.4 to 4 per 1000 normal births. Patients with CP require constant, long-term treatment and rehabilitation. Patients and methods: This study was conducted to determine the efficiency of a new method of locomotor therapy using the reduced gravity Krisaf device. The study group included 11 children of GMFCS I-III, the average age was 10.81 ±3.54 years (6-16 years), (4 males, 7 females). The average number of procedures per course was 8.71 ±1.25 (7-10). The average duration of the procedure was 36.11 ±6.97 (20-40) minutes. The assessment was conducted before and after the course of therapy using the Krisaf device. Spasticity was assessed using the Modified Tardieu Scale (MTS). The Edinburgh Visual Gait Score (EVGS) was used to assess gait. The Physiological Cost Index (PCI) and the ability to maintain balance on one leg (One-leg standing balance test (OLST)) were also assessed. Results: Krisaf therapy is efficient while treating motor function and affects gait according to the EVGS ($p = 0.02154$, $p < 0.05$) and changes in energy efficiency according to PCI ($p = 0.0293$, $p < 0.05$) and has not significantly affected spasticity measured by the MTS in this study. On the right $p = 0.5896$, on the left $p = 0.1056$. The results of maintaining balance according to the OLST were ambiguous. On the right leg, the time changed reliably ($p = 0.01403$), and on the left leg, the time changed insignificantly ($p = 0.4098$). Conclusion: The obtained results showed the influence of therapy using the Krisaf device on changing the gait and energy efficiency of movement.

Keywords

Krisaf, Cerebral palsy, Edinburgh Visual Gait Score

1. Introduction

Despite significant advances in neurology in recent years, cerebral palsy (CP) remains a pressing medical and social problem. CP is a group of non-progressive diseases that occur during the intranatal and postnatal periods and are manifested by varying degrees of nervous system disorders. This pathology was first described by Little in 1861. The frequency of CP incidence, according to different authors, ranges from 1.4 to 4 per 1000 normal births [1, 2]. The degree of nervous system disorders and the forms of CP manifestation are extremely diverse. There are various classifications of CP, but the most used classification of functional capabilities of patients for scientific and clinical purposes is the Gross Motor Function Classification System (GMFCS) [3], which divides patients with CP into five groups depending on their physical

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capabilities. Most patients with CP require constant rehabilitation and various methods of therapeutic and surgical treatment throughout their lives. Treatment and rehabilitation methods are very diverse and depend on the CP type, the patient's condition, the preferences of the attending physician, the equipment of the clinic, etc. However, there is still no unified, well-established rehabilitation protocol for patients with this condition. In the last 10-15 years, there has been a significant increase in the use of various robotic devices for the treatment of patients with CP [4-6]. All existing robotic systems allow for the rehabilitation of a patient in a standing [7] or sitting [8-10] position. The locomotor therapy system using the reduced gravity Krisaf device is the only system of robotic rehabilitation in a horizontal state and was developed primarily for the rehabilitation of patients with CP. The horizontal position of the patient during the rehabilitation process reduces the number of contraindications for this type of rehabilitation, simplifies the procedure for working with the patient, and reduces the spastic component during rehabilitation [11]. The operating modes of the Krisaf system allow for training various patterns of human movements, such as swimming, jumping, crawling, and walking. It is believed that the efficiency of using robotic systems is closely related to the "mechanisms of neuroplasticity", which allow "retraining" different parts of the central nervous system and improving or restoring some of the impaired functions [12]. Despite active research, robotic-assisted therapy in reduced-gravity conditions remains understudied, limiting the practical application of this approach. Therefore, the study intended to address this gap. This study was aimed at determining the influence of a course of therapy using the Krisaf device on the gait, spasticity, static function, and energy efficiency of movement in patients with CP. Most patients with CP suffer from various gait disorders, and gait analysis is the most important technique that can demonstrate the efficiency of therapy in such patients. Many methods of gait analysis can be applied; one of them is the Edinburgh Visual Gait Score (EVGS) [13]. This method is less complex and time-consuming than three-dimensional gait analysis and can be more widely used in clinical practice. In addition to gait disorders, spasticity is an important problem for patients. Reducing spasticity is one of the most important tasks in CP therapy, and it is very important to correctly assess spasticity for further prognosis and treatment of the patient. In most cases, spasticity assessment is not an easy task and the most used subjective scales in clinical practice for spasticity assessment are those by Ashworth and Tardieu [14]. In addition to the previously mentioned disorders, most patients have significantly higher energy consumption compared to healthy people, which is associated with high energy costs during abnormal gait; therefore, the effect of Krisaf therapy on energy consumption was also one of the goals of this study. The Physiological Cost Index (PCI) was used to assess energy consumption and energy efficiency of walking [15]. The ability of patients with CP to maintain balance was also assessed using the One-leg standing balance test (OLST) [16].

2. Patients and Methods

2.1. Patients

Eleven patients with CP were randomly selected from the rehabilitation center "Nadezhda". Four boys (36%) and seven girls (64%) took part in the study. The average age of the patients was (± SD) 10.81 ± 3.54 years. All patients suffered from spastic CP. The patients were divided into three groups according to the GMFCS. Group I included four patients, Group II - four patients, and Group III - three patients. The demographic data and distribution of the patients participating in the study by GMFCS groups are presented in Table 1.

Table 1. *Demographic data and distribution of patients by GMCFS groups.*

Parameters	Values
Age (± SD)	10.81 ± 3.54 years
Gender	male - 4 (36%), female - 7 (64%)
GMFCS I	4 (36%)
GMFCS II	4 (36%)
GMFCS III	3 (28%)

The treatment efficiency was determined by a few indicators, including the EVGS for assessing functional gait change. In the absence of computer analysis of kinematic data, the use of observational scales based on the study of goniometric data from video recordings of movements in orthogonal planes [10, 11] showed that the EVGS correlated with the Gillette Gait Index and the Gillette Functional Assessment Questionnaire walking scale (FAQ), which allowed it to be used for clinical purposes.

The scale represents an assessment of 15 criteria based on the results of video analysis: Initial Contact in Stance, Gait Profile Score, Heel Lift in Stance, Max Ankle Dorsiflexion in Stance, Hind-foot Varus/Valgus in Stance, Foot Rotation in Stance, Foot Clearance in Swing, Max Ankle Dorsiflexion in Swing, Peak Knee Flexion in Swing, Total Knee Range of Motion, Time to Peak Knee Flexion, Peak Hip Extension in Stance, Peak Hip Flexion in Swing, Pelvic Obliquity at Mid-Stance, and Pelvic Rotation at Mid-Stance. Patients walked barefoot on a flat surface, at their usual speed, with support if necessary. The study was conducted before and after the course of therapy.

The next scale for assessing the efficiency of therapy was the PCI. Children were asked to walk along a 24-meter track, and their heart rate (HR) was recorded before and after walking, as well as the time it took to walk the track. The PCI was calculated using the formula (Hw-Hr)/S, where Hw was the HR after walking, Hr was the HR before walking, and S was the walking speed in meters per minute. Normal values for the energy expenditure index were 0.4-0.6. A decrease in this indicator suggested an increase in the efficiency of walking.

The balance function was assessed using the OLST, with time measured using a stopwatch. Balance time was measured in seconds. The child was asked to maintain balance in a vertical position on one leg, alternately, first on the left, then on the right. The time was counted until the moment of loss of balance - touching the support with the free leg.

2.2. Research Protocol

All patients were prescribed a course of therapy using the Krisaf device. The average number of procedures per course was 8.71 ±1.25 (7-10). The average duration of one procedure on the Krisaf device was 36.11 ±6.97 minutes (20-40). A standard set of movement patterns, such as swimming, jumping, walking, and crawling, was used for all patients. Studies were conducted before and after the course of therapy to confirm the efficiency of therapy using the Krisaf device. In order to assess the change in gait patterns, patients underwent a gait test using the EVGS [13]. Spasticity analysis in patients in this study was performed using the Modified Tardieu Scale (MTS) [14]. The patient's ability to maintain balance was assessed by OLST [16]. The energy consumption and energy efficiency of the patient were assessed using the PCI [15]. All patients under study successfully completed the entire course of rehabilitation procedures on the Krisaf device. There were no exclusions from the study.

2.3. Data Analysis

All obtained data were analyzed using the R language version 4.2.2 and the RStudio computer program, Version 2023.12.1. In order to create a graphical representation of the data, standard tools of the R program and *ggplot2*, *ggpubr* libraries were used in this study. For comparing two data sets in gait and spasticity studies, the Wilcoxon test for paired samples was used.

3. Results

The following results were obtained during the study. When analyzing the gait by EVGS using the Wilcoxon paired test, statistically significant differences were obtained between the EVGS values before and after the therapy using the Krisaf device ($p = 0.02154$, $p < 0.05$). The differences are clearly visible in Figure 1.

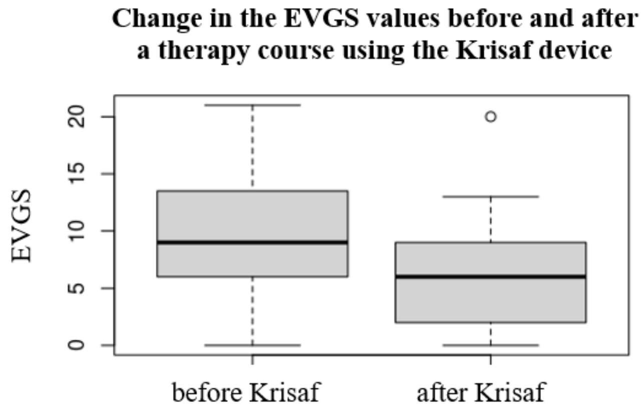

Figure 1. *Change in the EVGS values after a therapy course using the Krisaf device.*

Energy efficiency during walking after the course of therapy was measured by means of the PCI and changed statistically significantly ($p = 0.0293$, $p < 0.05$). Visible changes in energy efficiency values during walking measured by means of PCI are demonstrated in Figure 2.

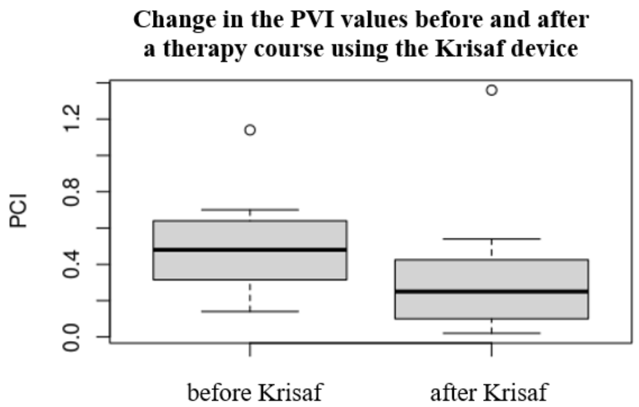

Figure 2. *Change in the PCI values after a therapy course using the Krisaf device.*

The balance study using the OLST demonstrated mixed results. Patients showed a significant improvement in balance when standing on the right leg ($p = 0.01403$, $p < 0.05$). On the left leg, this indicator was statistically insignificant ($p = 0.4098$). Spasticity measured by MTS before and after the course of therapy using the Krisaf device did not reveal statistically significant changes. On the right, the indicator was $p = 0.5896$, on the left, the indicator was $p = 0.1056$.

4. Discussion

The obtained statistically significant data on the change in gait according to the EVGS indicated that the course of therapy using the Krisaf device had a positive effect on the motor function of patients with CP. Such an effect might be associated, as it was previously mentioned, with the "neuroplasticity" of the central nervous system. Mechanical training on the Krisaf device could improve the synchronization of muscle activity of the lower limbs, which allowed improving the gait pattern. In addition to the positive change in the gait pattern after the locomotor therapy, a positive, statistically significant dynamics of the PCI ($p < 0.05$) was obtained. A decrease in the PCI values might indicate that the training course with the Krisaf device led to improved coordination of muscle contractions and a decrease in the chaotic contractions of the muscles of the lower limbs due to the same "neuro-plasticity", which in turn increased energy efficiency during movement in patients with CP. The results of the OLST showed contradictory, ambiguous results, without revealing a statistical difference between the first examination before using the Krisaf device and the final examination on the left leg. Despite this, it is necessary to continue researching this indicator in the future, increasing the number of patients in the study and clearly dividing the patients into GMFCS groups. The study did not reveal a decrease in spasticity in the patients studied. The reasons might be subjectivity in the measurement technique and insufficient therapy duration using the Krisaf device, which did not lead to a decrease in spasticity due to the improved coordination of the muscular apparatus. In the process of further research, it is important to conduct a study on a larger number of patients with CP, increase the duration of the course, and use not only subjective scales, but also objective methods for assessing spasticity, such as measuring muscle tone [17, 18] and specialized myographic tests [17]. Future studies are planned to continue investigating this rehabilitation approach for CP patients with expanded sample sizes.

5. Conclusions

The Krisaf device is an innovative means of rehabilitation of patients with CP, the technical implementation of which has no analogs. The conducted study demonstrated the efficiency of the therapy method using the Krisaf device. Therefore, complex robotic systems that allow simulating not only walking, but also phylogenetically more ancient locomotor patterns, have prospects for use in the framework of not only supportive, but also restorative concepts. In the observation group, statistically significant changes in the functional state of children were obtained: reduced energy costs for walking, improved gait pattern, and increased stability in an upright position. The method of locomotor therapy using the reduced gravity device can become one of the bases for the effective rehabilitation of children with CP. Further research is needed to create a scientific basis for scaling up the use of a new therapy method using the Krisaf device.

Abbreviations

CP	Cerebral Palsy
EVGS	Edinburgh Visual Gait Score
GMFCS	Gross Motor Function Classification System
MTS	Modified Tardieu Scale
OLST	One-Leg Standing Balance Test
PCI	Physiological Cost Index

Author Contributions

Zmanovskaya Vera Anatolyevna is the sole author. The author read and approved the final manuscript.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

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Conflicts of Interest

The author declares no conflicts of interest.

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Biography

Zmanovskaya Vera Anatolyevna is the head of a regional clinic specializing in the rehabilitation of children with central nervous system disorders and musculoskeletal conditions, as well as an associate professor at Tyumen State University. In 2012, she completed her postgraduate studies and defended her candidate's dissertation. She is recognized for her exceptional contributions to the study of cerebral palsy and related motor system disorders. In recent years, she has participated in numerous research studies on the therapy of children with cerebral palsy. Currently, she is a member of the Expert Council on Cerebral Palsy and Related Movement Disorders and a speaker at national and international conferences.

Research Field

Zmanovskaya Vera Anatolyevna: Management of spasticity in children with cerebral palsy; organization of assistance to children with spinal muscular atrophy; treatment of children with short bowel syndrome; assistance to children after multilevel skeletal surgeries; organization of observation of children with cerebral palsy.