ROBOTIC MECHANOTHERAPY IN STAGED REHABILITATION OF PATIENTS WITH CONSEQUENCES OF SPINAL CORD INJURY

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Objective. To analyze the outcomes of early rehabilitation of patients with consequences of spinal cord injury using robotic technology.
Material and Methods. A total of 122 patients with consequences of spinal cord injury having movement disorders were examined and treated in the rehabilitation department of the Novosibirsk RITO. Group 1 included 59 patients treated with the standard version of rehabilitation program, while the program used in Group 2 (63 patients) involved longer and more careful preparation for sessions on the Lokomat machine and consisted of three stages of treatment — prehospital, preliminary and main ones.
Results. The course of rehabilitation therapy had positive effect on the dynamics of neurological symptoms. Indicators of positive dynamics were statistically significantly higher in patients of Group 2. Data of electrophysiological study also showed that the optimized treatment program was more effective in restoring lost functions of the spinal cord. Optimization of rehabilitation and preconditioning of patients to loads decreased frequency of adverse reactions (orthostatic and fever responses, increase in pyramidal muscle tone in lower extremities) in comparison with the standard approach.
Conclusion. Optimized course of rehabilitation therapy positively affected the dynamics of neurological symptoms.
Key Words: spinal cord injury, robotic mechanotherapy, orthostatic response, fever response, pyramidal muscle tone.

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The incidence of spinal cord injuries in Russia is 8000 cases per year. About half of the injured persons survive, but 80 % of them subsequently have disability status (grade I or II) [1, 6]. The effectiveness of the recovery of patients with movement disorders associated with the consequences of spinal cord injury (SCI) is determined by the severity of neurological deficits [2]. Discoordination of cortico-subcortical associations leads to the predominance of the pyramidal tone in the lower extremities and these patients demonstrate autonomic dysfunction and reduced tolerance to physical load [2, 5], so that the standard exercises can trigger muscle spasticity of the lower limbs, as well as various orthostatic reactions [1]. All this determines the search for effective high-tech methods, including robotic systems, but the lack of practical experience limits their widespread use [4].

The study was aimed at analyzing the results of medical rehabilitation of patients with the consequences of the SCI using robotic technology in the early recovery period.

Material and Methods

A total of 122 patients aged 18–60 years (mean age 36.2 ± 2.4 years) with pareses and conduction sensitivity disorders in the early recovery period of the SCI were treated at the Novosibirsk RITO during two years.

The dynamics of treatment was controlled in all patients by assessing the somatic status and neurological deficit on the ASIA scale, assessing spasticity on the Ashworth scale, electroneuromyography using Neuropack-2 instrument, recording of cortical somatosensory evoked potentials on the stimulation of the tibial and peroneal nerves.

All patients were divided into two groups depending on the treatment method. Neurological deficit (ASIA grade C or D) with movement disorders was a criterion for inclusion in the treatment program. Contraindications included body mass of more than 130 kg or less than 30 kg, height 200 cm and above, pronounced body asymmetry (lower limb length difference of 2 cm and above), pronounced spinal deformity (grade III–IV scoliosis, etc.), joints contractures, grade III–IV osteoporosis, arthropathy (grade III–IV arthritis, aseptic necrosis of the femoral head, dysplasia, etc.), arthrodesis of the joints of the lower extremities, soft tissue lesions (decubital necrosis, etc.), cancer, decompensated internal diseases, cognitive disorders, and epilepsy.

Group 1 included 59 patients, who used the original version of the program: neurometabolic therapy (cholinesterase inhibitors, antioxidants, nootropics, angioprotectors, B vitamins), massage of the back, upper and lower limbs, physiotherapy (magnetotherapy, electromyostimulation, electrophoresis), therapeutic exercise complexes on a mat (exercises for coordination, strengthening of back and lower limb muscles), training on the Balance Trainer exerciser and on the Lokomat robotic complex for the induced walking for 20 minutes a day, five days a week. Training on Lokomat was started during the first week of treatment.

Group 2 included 63 patients, who used a program with longer and more thorough preparations for exercises on the Lokomat device, consisting of prehospital, preliminary, and main stages.

During the prehospital (I) stage, the patients with muscle tone as high as three or more points on the Ashworth Scale were administered with muscle relaxants (the standard regimen of baclosan, tolperisone) and session of the relaxing lower limb massage.

Preparatory (II) stage included exercises with an exercise therapy instructor to strengthen back and lower limb muscles for 30 minutes once a day, back and lower limb massage, exercises on the Balance Trainer for 20–30 minutes once a day, muscle relaxants (standard regimen of baclosan) were administered in the case of high muscle tone (2 points and above on the Ashworth scale) and frequent synkinesias. Duration of this phase was one week.

The main (III) stage was a three-week course of exercises using Lokomat (15–30 minutes-long daily sessions five times a week). During the first week, the parameters were adjusted with allowance for patient's individual characteristics: the size of the device orthoses and bindings, weight unloading on the Lokomat device at the initial rate of 50–70 % of body weight, length, width, and frequency of steps. Walking speed was initially set at 1.5 km/h. During the second week of exercises, patient's body weight unloading was reduced by 5 kg every 2–3 days and the power of the device was reduced from the original 100 % by 5–10 % once per 2–3 days. The patient's exercises included march walking, trying to stamp a foot and to kick the ball.

During the third week of training, body weight unloading and the device power were reduced by 5–10 % every 2–3 days, until body weight unloading reached 15–20 kg and device power was reduced to 50 %. At this stage, the exercises were carried out with changing walking speed, including the use of additional tools (dumbbells, weighting tools for the upper limbs weighing 0.5–1 kg).

The criteria to stop increasing load included patient's complaints of general weakness, dyspnea, cramps in the lower limbs, as well as body temperature above 37.0 °C and labile hemodynamic parameters (variation in blood pressure by 20 % with respect to the individual standard values, increase in heart rate above 100 bpm).

At the baseline, all patients had severe neurological disorders in the form of motor deficit: in Group 1, they corresponded to ASIA grade C in 61.0 % of patients, ASIA grade D in 39.0 % of patients; in Group 2, it was 66.7 % and 33.3 %, respectively. There was pyramidal increase in lower extremities tone (1–2 points on the Ashworth scale) in 78.7 % (96) of patients, autonomic dysfunction syndrome in the form of hypotension, fatigue, hyperhidrosis, and angiodystonic cephalgia in 22.1 % (27) of patients.

The statistical data processing was performed using the Statistica software (Version 10), Fisher's exact test, and paired Wilcoxon test. The significance of differences was assessed based on the confidence level of $p < 0.05$.

Results and Discussion

Group 1 patients demonstrated orthostatic reactions in the form of a blood pressure below 90/60 mm Hg after the exercise course in 40.7 % of cases, fever up to 37.5–38.0 °C in 10.2 % of patients. It should be noted that, while all patients had pyramidal increase in lower limb muscle tone (2.3 ± 0.5 points on the Ashworth scale) at the baseline, 62.7 % of them demonstrated increase in spasticity by 3.1 ± 0.4 points after exercises.

Post-treatment orthostatic reaction was 3.7 times less frequent in Group 2 patients compared to the baseline data and was observed in 11.1 % and 40.7 % of cases, respectively ($p < 0.05$). Fever response after loading was observed in 3.2 % of patients, which was also 3.2 times lower compared to 10.2 % obtained in Group 1 patients ($p > 0.05$). In 96.8 % of patients, blood pressure and temperature were within the normal range, i.e. there was virtually no orthostatic reaction. Along with this, increase in the pyramidal muscle tone from 2.0 ± 0.3 to 3.3 ± 0.4 on the Ashworth scale was significantly less common and occurred in 31.8 % of patients compared to 78.7 % prior to the rehabilitation treatment ($p < 0.05$).

The course of rehabilitation therapy has positive effect on the dynamics of neurological symptoms; in Group 2 patients, positive dynamics parameters were significantly higher.

For example, the number of Group 1 patients, whose condition improved from ASIA grade C (more severe) to grade D (less severe), amounted to 6.8 %, while the number of patients without neurological deficit (ASIA grade E) was 1.7 %. In Group 2, the number of patients with type D neurologic deficit increased by 20.7 %; at the same time, there was no neurological deficit after the course of treatment in 6.4 % of patients (Table).

According to the results of electro-neuromyography, the activity of maximal voluntary tension of foot and leg muscles, both flexors and extensors, improved after the treatment. Increase by more than 15.0 % was detected in 13 (36.1 %) Group 1 patients with ASIA C neurological deficit, and 15 (65.2 %) patients with ASIA D deficit.

In Group 2, the corresponding results were 69.0 % for ASIA C and 85.7 % for ASIA D. These results are indicative of higher effectiveness of the two-stage treatment in patients with the most significant neurological deficits.

Along with increase in the amplitude of the interference curves of tension activity, improvement of their frequency composition, deceleration, and clustering was observed.

By the end of the course of treatment, changes in conduction velocity in the tibial and peroneal nerves were compared in Group 1 and Group 2 patients. Initially, these values significantly varied within each group of patients, which was associated with location of spinal cord injury, its prescription, etc. The values both higher and substantially lower than the lower limit of 40 m/s were recorded, and therefore the average values of conduction velocity changes in these nerves were compared in each patient as a percentage of the values recorded prior to the treatment. The average excitation conduction velocity in the sciatic nerve branches increased after the course treatment by 5.2 % in Group 1 patients and by 14.3 % in Group 2 patients.

The study of the evoked potentials at the beginning of the main phase of treatment in these patients showed reduced amplitude of evoked potentials with increased delay; the average delay values were substantially higher compared to those in healthy subjects (44.9 ms in Group 1 patients, 45.1 ms in Group 2 patients; the normal value is 39 ms). No less than a third of cases showed different delays in response to stimulation of left and right limb nerves [3]. During the four-week-long course of treatment, there was no significant dynamics of the delay time in Group 1 and Group 2 patients; at the same time, there was a trend towards an increase in amplitude and normalization of the form of evoked potentials and decrease in the duration of the main positive components of P39. Follow-up examination in 10—12 months showed decrease in delay time by 2.0 % in Group 1 patients and 9.2 % in Group 2 patients.

Electrophysiological studies have also shown that the optimized treatment regimen was more effective in restoring lost functions of the spinal cord. Additionally, optimization of rehabilitation measures and pre-exercise preparation of patients reduced the incidence of adverse reactions.

Conclusions

1. Three-stage approach to the organization and carrying out the rehabilitation of patients with the consequences of SCI with strict observance of the indications and contraindications to treatment and pre-exercise preparation led to 3.7-fold decrease in the incidence of orthostatic reactions, 3.2-fold — fever response, and 1.97-fold — increase in the pyramidal muscle tone in the lower extremities (compared to the standard approach).
2. The course of rehabilitation therapy had a positive impact on the dynamics of neurological symptoms; they significantly regressed in Group 2 patients.
3. According to the results of electroneuromyography, rehabilitation treatment resulted in improvement of the average conduction velocity in the sciatic nerve branches by 5.2 % in Group 1 and by 14.3 % in Group 2.

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Table

Neurological deficit in patients with consequences of spinal cord injury after a 4-week course of rehabilitation, n (%)

ASIA grade of neurological deficit	Group	Baseline	Over time	Statistical significance
C	1st	36 (61.0)	31 (52.5)	0.40
	2nd	42 (66.7)	25 (39.7)	0.002*
D	1st	23 (39.0)	27 (45.8)	0.14
	2nd	21 (33.3)	34 (54.0)	0.02*
E	1st	0	1 (1.7)	0.50
	2nd	0	4 (6.4)	0.06

*the differences are significant, $p < 0.05$.

References

1. **Belova AN.** Neurorehabilitation: Guideline for Physicians. Moscow, 2000. In Russian.
2. **Daminov VD, Kucherenko SS, Sagildina YuO, Kuznetsov AN.** Robotic technologies in rehabilitation of patients after surgical revascularization of brain. Journal of Restorative Medicine and Rehabilitation. 2012;(2(48)):29–31. In Russian.
3. **Zenkov LR, Ronkin MA.** Functional Diagnosis of Nervous System Diseases. Moscow, 2004. In Russian.
4. **Kankulova EA, Daminov VD, Zimina EV, Kuznetsov AN.** Transcranial cerebral electrical stimulation combined with robotic mechanotherapy. Doctor.Ru. 2010;(8(59)):48–50. In Russian.
5. **Karepov GV, Gorbunov VI, Karepova ID.** Dynamics of vegetative reactions in patients with traumatic spinal cord disease during balneo-mud therapy. In: Balneology and Physiotherapy. Kiev, 2007;20:23–26. In Russian.
6. **Leontiev MA.** Surgical correction of foot pathology in the complex of motor rehabilitation in patients with lower paraplegia: Abstract of MD/PhD Thesis. Novokuznetsk, 2003. In Russian.

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