# THE USE OF THE BALANCE TUTOR REHABILITATION TREADMILL FOR BALANCE AND GAIT RECOVERY IN POSTSTROKE PATIENTS

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State-of-the-art rehabilitation equipment offers a wide range of static and dynamic exercise programs for fall prevention by improving balance control during standing or walking. Our study aimed to provide a rationale for the use of the BalanceTutor rehabilitation treadmill to improve static and dynamic balance in patients who had suffered an acute cerebrovascular accident. The study included 72 patients with postural balance impairments in their late recovery period. In the experimental group, center of pressure (COP) sway area and COP velocity decreased significantly, measured with patients' eyes opened ($p = 0.0476$ and $p = 0.0176$, respectively) and closed ($p = 0.0072$ and $p = 0.0037$, respectively). At the end of the rehabilitation program, we observed a statistically significant increase in the electromyographic signal amplitude on the stroke-affected side of the body in *m. peroneus longus* ($p = 0.0117$), consistent with the regained muscle strength in the lower extremities of the affected body side measured by McPeak and Veyss 6-point scales. Tinetti gait and balance scores also improved ($p = 0.0513$ and $p = 0.0274$, respectively). Thus, the use of the BalanceTutor treadmill in the rehabilitation of poststroke patients proves to be effective and reasonable.

**Keywords:** acute cerebrovascular accident, postural balance, equipment for improving static and dynamic balance

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# ПРИМЕНЕНИЕ РЕАБИЛИТАЦИОННОЙ СИСТЕМЫ BALANCE TUTOR ДЛЯ ВОССТАНОВЛЕНИЯ ФУНКЦИИ РАВНОВЕСИЯ И ХОДЬБЫ У ПАЦИЕНТОВ ПОСЛЕ ОСТРОГО НАРУШЕНИЯ МОЗГОВОГО КРОВООБРАЩЕНИЯ

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Современное оборудование позволяет проводить координаторные тренировки в статическом и динамическом режиме с целью профилактики падения в статике и при ходьбе. Целью исследования стало обоснование применения системы для восстановления статического и динамического равновесия BalanceTutor у пациентов с последствиями острого нарушения мозгового кровообращения. Обследованы 72 пациента с нарушением постурального баланса в позднем восстановительном периоде. В основной группе отмечено статистически значимое уменьшение площади статокинезиограммы и скорости перемещения центра давления как в положении «глаза открыты» ($p = 0{,}0476$ и $p = 0{,}0176$ соответственно), так и в положении «глаза закрыты» ($p = 0{,}0072$ и $p = 0{,}0037$ соответственно). К окончанию курса реабилитации в основной группе зафиксировано достоверное увеличение амплитуды кривой максимального мышечного напряжения на стороне двигательных нарушений в *m. peroneus longus* ($p = 0{,}0117$), что было сопоставимо с увеличением мышечной силы в нижних конечностях пораженной стороны согласно 6-балльной шкале оценки мышечной силы (по L. McPeak; M. Вейсс). Отмечено улучшение показателей походки ($p = 0{,}0513$) и устойчивости ($p = 0{,}0274$) по шкале Тинетти. Применение системы BalanceTutor в комплексной реабилитации пациентов с последствиями острого нарушения мозгового кровообращения является эффективным и целесообразным.

**Ключевые слова:** острое нарушение мозгового кровообращения, постуральный баланс, система для восстановления статического и динамического равновесия

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The most frequent consequences of acute cerebrovascular accidents (ACAs) that lead to disability are motor and coordination impairments. They affect 81.2 % of total patients. One of the main goals of poststroke medical and social rehabilitation is to restore staticolocomotory functions that determine social independence and labor ability of the patient [1–3]. For some years now, stabilometric platforms and virtual reality have been used to restore patients' static balance after ACA [4–6].

Rehabilitation specialists from different countries have proposed methods for postural balance training designed to activate reactive postural synergies that prevent a person from falling through returning the center of gravity to the base of support by making a step in the direction of the fall. Such coordination exercises train the patient’s ability to adapt to sudden balance destabilization while walking on the treadmill (forward and backward perturbations) or standing on the platform (sideways perturbations) [7–13].

The use of modern equipment in rehabilitation allows static and dynamic coordination training with simultaneous correction of the movement pattern by initiating an unexpected postural disturbance through destabilization at a certain phase of the step [14]. BalanceTutor (MediTouch, Israel) (Fig. 1) is a promising system designed for postural control training, correction of motor stereotypes and falls prevention in poststroke patients.

The aim of the study was to provide a rationale for the use of BalanceTutor rehabilitation treadmill in the treatment of patients suffering ACA sequelae.

## METHODS

The study was conducted in Shvetsova Research and Care Center for Medical and Social Rehabilitation of the Disabled from March to June 2017. The study included patients with central hemiparesis (mild to moderate) after middle cerebral artery ACA (occurred less than 1 year before the study) with impaired postural control.

**Fig. 1.** BalanceTutor

The exclusion criteria were:

- patient's weight over 135 kg;
- contractures of the lower limbs joints;
- recent endoprosthesis of large joints;
- unconsolidated spinal and limb fractures, unstable osteosynthesis;
- open skin lesions on the lower extremities and torso;
- respiratory or and cardiovascular decompensation;
- severe vascular disorders of lower extremities (thrombophlebitis, phlebothrombosis);
- marked osteoporosis;
- end-stage kidney or liver disease;
- severe cognitive impairment, avoidance or aggressive behavior, psychoorganic syndrome;
- prescribed bed rest.

The study recruited 72 patients with impaired postural control at the late stage of rehabilitation following middle cerebral artery ACA. The patients were randomly divided into two comparable groups. The treatment group consisted of 37 patients (mean age of 58.0 ± 5.3 years); the control group included 35 people (mean age of 56.0 ± 4.8 years). In the treatment group, 30 (81.1 %) patients had ischemic stroke, 7 (18.9 %) — hemorrhagic stroke. In the control group 27 patients (77.1 %) had ischemic stroke and 8 (22.9 %) suffered hemorrhagic stroke. The treatment group included 20 (54.1 %) men and 17 (45.9 %) women, the control group included 18 (51.4 %) men and 17 (48.6 %) women. The disease duration was 6.8 ± 0.4 months in the treatment group and 6.4 ± 0.2 months in the control group.

The following methods and devices were used to assess the effectiveness of the proposed rehabilitation system: electroneuromyography (ENMG), done with Neuromyograph-01-MBN, four-channel electroneuromyography hardware and software set designed by MBN Medical Research Firm, Russia; stabilometry, done with MBN Stabilo hardware and software (Stabilometry package) set designed by MBN Medical Research Firm, Russia; L. McPeak and M. Weiss 6-point muscle strength assessment scale; Ashworth scale of muscle spasticity (interpretation by R. Bohannon, V. Smith, D. Wade); Tinetti score.

All patients were undergoing the same rehabilitation program that included symptomatic drug therapy, physiotherapy (magnetotherapy, paraffin treatment, massage of the affected limbs and reflex zones), physical training (gymnastics to improve coordination function, cyclic mechanotherapy for upper and lower extremities). In addition, the patients in the main group had 20 minute sessions on BalanceTutor (18 sessions, 6 per week).

We developed a method for coordination training that makes use of BalanceTutor and aids in restoration of static and dynamic balance [15]. The exercises were dynamic "trigger exercises" in the "compensatory response" mode aimed to elicit compensatory stepping with the affected limb. The load on the lower limbs was distributed using feedback sensors, which also allowed monitoring of the spatial position of the limbs. Training required patient maintaining balance while walking on the treadmill with the body oriented forward (Fig. 2A, B) and sideways (Fig. 2C).

In the course of rehabilitation, the values of the operating parameters of the system were gradually increased, including the perturbation amplitude, speed of the treadmill, and session duration. The first session lasted for 10 minutes, with the patient walking straight for 7 minutes (Fig. 2A, B) and then stepping laterally towards the affected limb for 3 minutes (Fig. 2C). Every 4th session the perturbation amplitude was increased. From the 4th session, lateral perturbations were set to 15 cm in each direction; forward and backward perturbations were within 10 cm in each direction; session's duration was increased to 12 minutes (8 minutes of straight walking, 4 minutes of lateral stepping). From the 8th session, lateral perturbations were set to 18 cm in each direction; forward and backward perturbations were within 13 cm in each direction; session's duration was increased to 15 minutes (10 minutes of straight walking, 5 minutes of lateral stepping). From the 12th session, lateral perturbations were set to 20–22 cm in each direction; forward and backward perturbations were within 15–17 cm in each direction; session's duration was 20 minutes (13 minutes of straight walking, 7 minutes of lateral stepping).

Before allowing patients into the study, they were informed of the purpose and nature of the clinical study, diagnostic methods and components of the rehabilitation program, research effectiveness and safety, benefits and risks implied, patients' rights and responsibilities. All patients who agreed to participate in the study have given their informed consent.

Ethical review of the research protocol (including the informed consent form) was carried out by the local ethics committee of Pirogov Russian National Research Medical University (Protocol No. 163 of March 20, 2017). Members of the local ethics committee gave their approval.

To process the results, a database was generated using Microsoft Excel 2007 software. The database included 24 parameters for 72 patients. Patients' data were entered into the database before the rehabilitation course, in the middle of the course (after the 10th session) and after it had been completed, the only exception being electroneuromyography, which was performed twice (before and after the rehabilitation course). The obtained results were processed using StatSoft Statistica 10.0. Normality was tested using Kolmogorov–Smirnov and Shapiro–Wilk tests. The samples did not have a normal distribution, so Mann–Whitney, Wilcoxon, and Friedman tests were applied. The Mann–Whitney U was used to evaluate the differences between the treatment group and the controls. The groups were compared three times: before the rehabilitation course, after the 10th procedure and when the rehabilitation course was over. To compare electroneuromyography data for statistical differences before and after the rehabilitation course, the Wilcoxon matched pairs test was used. Since patients' data were collected repeatedly at three different time points, the Friedman test was applied separately to the treatment group and the controls. The differences were considered statistically significant at $p < 0.05$. When the Friedman test revealed significant differences in the parameters over the course of study, the Wilcoxon test was applied to determine when (between what time points) those differences were registered. Multiple comparisons were accounted for using the Holm-Bonferroni method when determining the critical level of significance.

## RESULTS

Neuromyography was performed on the electroneuromyography machine for data recording and processing. Electromyograms (EMGs) of muscles of the upper (*m. opponens pollicis*) and lower (*m. peroneus longus*) limbs were recorded at rest and during active contractions of the muscles. Electromyograms were analyzed using a classification by Yu. S. Yusevich. Electroneuromyography aimed to determine the speed of impulse going through peripheral motor nerves (*n. medianus*, *n. peroneus*) and the amplitude, latency and duration of the evoked response in the muscles of the upper and lower limbs.

EMG revealed that poststroke patients had weaker electrogenesis in the muscle groups examined (*m. opponens pollicis*, *m. peroneus longus*): the amplitude of biopotentials was almost twofold smaller compared to normal values.

Analysis of electroneuromyography data revealed that poststroke patients had the amplitude of median nerve motor response reduced by an average of 50 % to 1.73 ± 0.6 mV, that of the peroneal nerve — by 40 % to 2.09 ± 0.8 mV.

Regression of paretic symptoms on the affected body side over the course of rehabilitation was consistent with the favorable dynamics of neurophysiological data. Patients undergoing rehabilitation with BalanceTutor showed improvement in electroneuromyographic and electromyographic parameters. After the rehabilitation, these patients had an increased amplitude of the maximum muscle strain curve on the side suffering from motor disturbances: up to 243.7 ± 18.6 µV in *m. opponens pollicis* and 447.3 ± 24.7 µV in *m. peroneus longus*, as registered by EMG (Fig. 3). Before the course, the curve amplitude in this group was 181.9 ± 17.0 µV in *m. opponens pollicis* ($p = 0.0491$, the Wilcoxon test) and 236.7 ± 22.0 µV in *m. peroneus longus* ($p = 0.0117$, the Wilcoxon test). By the end of the rehabilitation course, 5 (13.5 %) patients from the main group had the curve amplitude on the affected side comparable to that on the healthy side: 317.4 ± 18.2 µV for the upper limb (*m. opponens pollicis*) and 538.2 ± 24.2 µV for the lower limb (*m. peroneus longus*). Before the course, all patients included in the main group showed a smaller amplitude of the muscle strain curve. In the control group, the amplitude of the maximum muscle

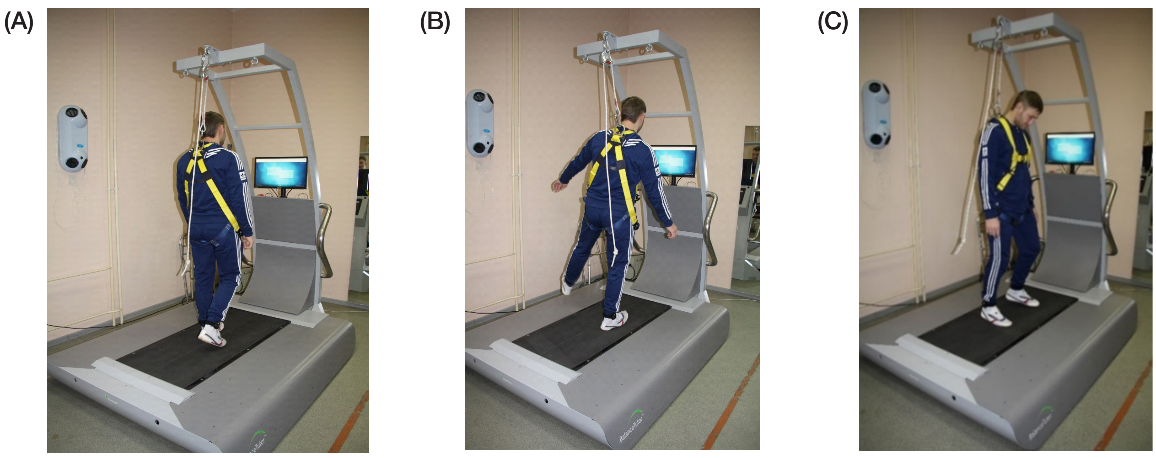

**Fig. 2.** Exercising with BalanceTutor

strain curve before rehabilitation was 178.9 ± 19.0 μV in *m. opponens pollicis* and 226.5 ± 21.0 μV in *m. peroneus longus*. After the rehabilitation, the amplitude on the side suffering from motor disturbances increased to 197.3 ± 18.1 μV in *m. opponens pollicis* (p = 0.0791, the Wilcoxon test) and 277.3 ± 23.7 μV in *m. peroneus longus* (p = 0.0511, the Wilcoxon test). In both cases, no statistically significant differences were observed.

In both groups, ENMG registered no changes in the speed of the pulse conducted by motor fibers, latency and duration of motor response before and after rehabilitation. The rehabilitation course with BalanceTutor sessions included stimulated the increase of the amplitude of median nerve-conducted motor response in the paretic side to 2.5 ± 0.9 mV, compared to 1.87 ± 0.50 mV in the controls (p = 0.0563, the Mann–Whitney test). Before the course, the amplitude of median nerve-conducted motor response in the treatment group was 1.8 ± 0.7 mV and 1.8 ± 0.7 mV in the control group. By the end of rehabilitation, the amplitude of the motor response going through the peroneal nerve in the treatment group (paretic side) increased to 2.97 ± 0.90 mV, in the control group — to 1.97 ± 0.50 mV (p = 0.0063, the Mann–Whitney test). Before the rehabilitation course, this parameter in the treatment group equaled 1.87 ± 0.80 mV and was 1.78 ± 0.80 mV in the control group.

Stabilometry was performed in compliance with the requirements established by the Moscow Stabilometry Consensus [16]. Postural performance was evaluated with patients standing on the stabilization platform on both legs. Romberg ratios and the following parameters were calculated: center of pressure (COP) sway area and COP velocity, measured with patients' eyes opened (EO) and closed (EC). The analysis of the stabilometry data obtained before the rehabilitation course revealed that both COP sway area and COP velocity were significantly abnormal for both EO and EC positions. In the treatment group, the COP sway area (EO) was 120.40 ± 31.24 mm², which is above normal values, and that of the control group equaled 123.16 ± 34.87 mm². The COP velocity (EO) was also above the norm: 18.63 ± 1.79 mm/s in the treatment group and 18.09 ± 1.99 mm/s in the control group. With patients' eyes closed, the abnormality of stabilometric parameters increased significantly in both groups. The COP sway area (EC) in the treatment group increased to 254.5 ± 27.5 mm² and to 269.86 ± 32.71 mm² in the control group. The COP velocity (EC) was 28.25 ± 2.56 mm/s and 29.61 ± 4.03 mm/s, respectively. Functionally, prior to the rehabilitation all patients had poor postural control in the upright position. Romberg ratios were high, 211.37 ± 16.24 % in the treatment group and 219.11 ± 20.31 % in the control group, indicative of insufficient control exerted by the proprioceptive

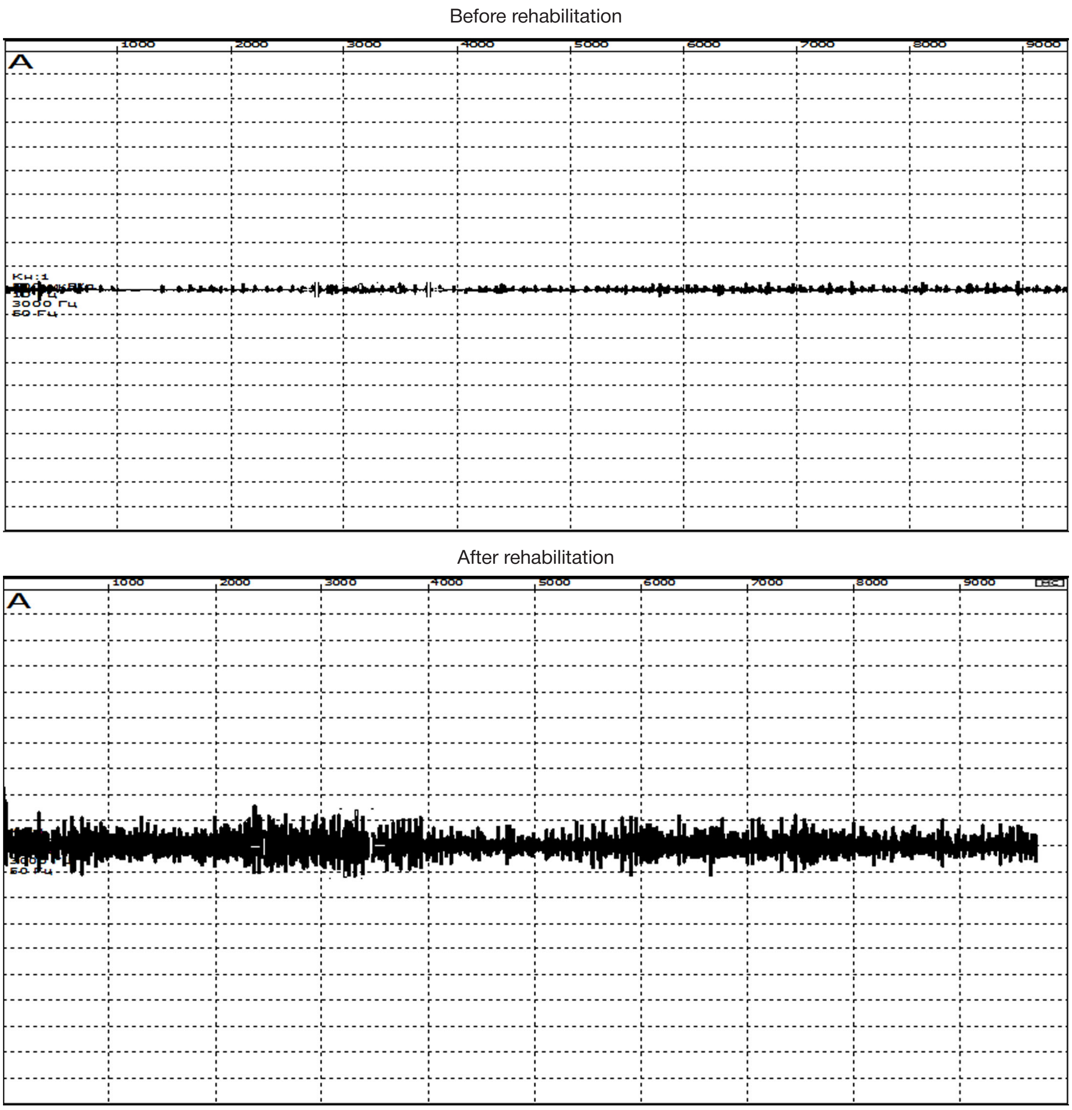


**Fig. 3.** Electromyography data of a patient of the treatment group for m. peroneus longus before and after rehabilitation

system. This means that maintaining balance was largely dependent on the visual perception system. In the middle of the rehabilitation course, sustainable positive changes in the COP sway area, COP velocity (EO and EC) and Romberg ratios were registered in both groups, although the differences were not statistically significant.

After the rehabilitation course with BalanceTutor sessions, improvements of stabilometric parameters became obvious. The COP sway area (EO) decreased in both groups, but the dynamics were more pronounced in the treatment group: 82.30 ± 21.43 mm$^2$ against 115.40 ± 31.56 mm$^2$ in the control group ($p = 0.0476$, the Mann–Whitney test). The reduction in the COP sway area (EC) was statistically significant and greater in the treatment group: 160.45 ± 24.63 mm$^2$ as opposed to 247.58 ± 41.39 mm$^2$ in the control group ($p = 0.0072$, the Mann–Whitney test). These data are evident of the increasingly important role played by the proprioceptive system in maintaining a vertical stance and of some improvements in the visual-motor connection. The downward tendency of Romberg ratios seen by the end of the rehabilitation course supports the aforementioned data. The tendency was more obvious in the treatment group: 194.91 ± 21.62 % vs. 214.54 ± 19.74 % in the control group ($p = 0.0798$, the Mann–Whitney test, differences statistically insignificant). By the end of the course, both groups showed improvement in the COP velocity. However, a statistically significant decrease in the COP velocity was observed in the treatment group only: with patients' eyes opened, it equaled 11.09 ± 1.06 mm/s while in the control group the value was 17.05 ± 1.42 mm/s ($p = 0.0176$, the Mann–Whitney test); with patient's eyes closed, the COP velocity in the treatment group was 18.09 ± 2.08 mm/s, in the control group — 27.91 ± 4.50 mm/s ($p = 0.0037$, the Mann–Whitney test). Lower COP velocity after the rehabilitation signals improvement of the static balance and stability of the patients. This result was more evident in the treatment group.

Muscle strength dynamics and paresis severity were assessed using the 6-point scale by McPeak and Weiss). After the rehabilitation, both groups demonstrated increased muscle strength in the limbs; this fact was consistent with the increasing the number of patients whose condition improved from moderate to mild paresis. Statistically significant changes in muscle strength in the affected lower limb were registered in the treatment group. After the rehabilitation, mild paresis of lower limbs was observed in 33 (89.2 %) patients of the treatment group, compared to 18 controls (51.4 %) ($p = 0.0247$, the chi-squared test with Yates correction). Before the rehabilitation course, 13 (35.1 %) patients of the treatment group and 12 (34.4 %) controls had mild paresis of the lower limbs; 24 (64.9 %) patients of the treatment group and 23 (65.7 %) controls had moderate paresis. As for the upper limbs on the paretic side, the only improvement registered was an increase of muscle strength, slightly more pronounced in the treatment group. In the middle of the rehabilitation course, patients from both groups showed greater muscle strength in the affected limbs; the most noticeable improvement was registered for the lower limbs in patients included in the treatment group (Fig. 4).

The complex rehabilitation of patients with impaired postural balance after ACA aided muscle tone changes in paretic limbs detected using the Ashworth scale of muscle spasticity (Bohannon, Smith, Wade). Prior to the rehabilitation, the patients in both groups had spasticity corresponding to a moderate tone increase: the average muscle tone score for the upper limb in the treatment group was 3.25 ± 0.48, in the control group — 3.31 ± 0.53; the average muscle tone score for the lower limb was 3.04 ± 0.38 in the treatment group and 3.11 ± 0.42 in the control group. The 10th session marked a slight spasticity reduction in the affected limbs in both groups. By the day of discharge, patients in both groups demonstrated a considerably decreased muscle tone in the affected limbs; the changes were statistically significant mostly for the lower limb in the treatment group ($p = 0.0041$, the Friedman test). For the lower limb, the average muscle tone score was 2.29 ± 0.23 in the treatment group and 2.82 ± 0.39 in the control group; for the upper limb, the tone scores were 2.88 ± 0.38 and 2.93 ± 0.41, respectively.

The Tinetti test was used to measure performance of static and dynamic motor tasks and the severity of balance impairment. At the time of admission to the rehabilitation center, the patients scored 11.42 ± 0.26 and 15.87 ± 0.31 points for gait and stability, respectively (the treatment group); the controls scored 11.38 ± 0.28 and 15.58 ± 0.34 points, respectively, which corresponds to moderate impairment. In the middle of the course, sustainable positive changes in gait and stability were registered in both groups, although the differences were not statistically significant. By the end of the rehabilitation, the Tinetti test revealed positive changes in both groups. The treatment group showed more stable and marked results: the scores tended to shift towards mild impairment, with gait score at 14.97 ± 0.28 points ($p = 0.0513$, the Wilcoxon test) and stability at 21.90 ± 0.37 points ($p = 0.0274$, the Wilcoxon test). As for the control group, their gait and stability also improved, but the values stayed within the

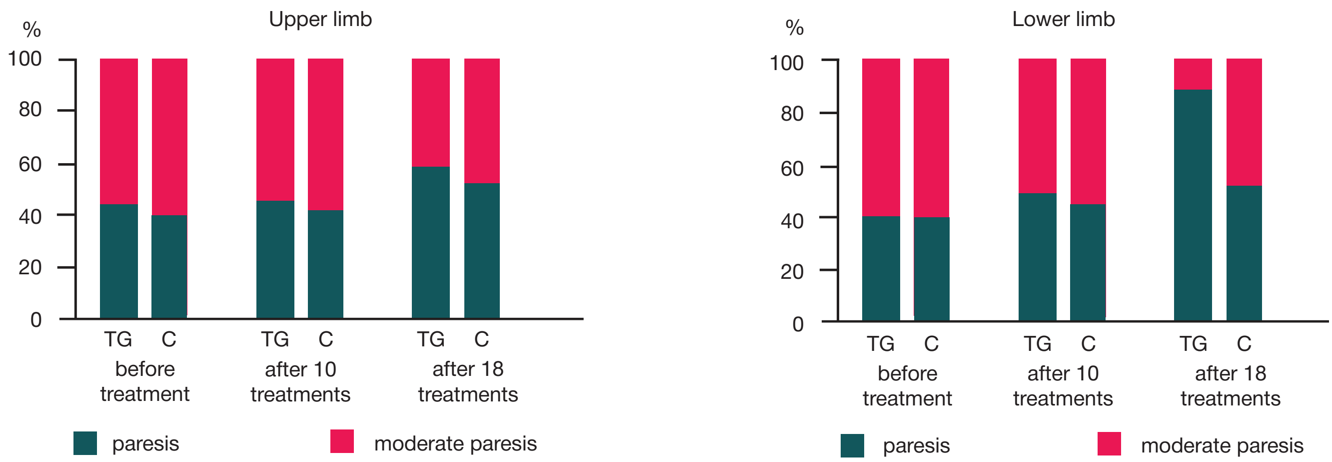


**Fig. 4.** Severity of limb paresis at different stages of the rehabilitation (TG — treatment group, C — controls)

limits typical for moderate impairments: 12.02 ± 0.29 points ($p = 0.0931$, the Wilcoxon test) and 17.02 ± 0.27 points ($p = 0.0671$, the Wilcoxon test), respectively. In both cases, no statistically significant differences were found.

## DISCUSSION

In recent years, a number of studies have addressed methods based on the use of the stabilometric platform and virtual reality in the rehabilitation of poststroke patients, aimed at restoring their static balance. Such methods can be used for improving the static balance only, meaning that there is a need for dynamic balance restoration techniques. Nevertheless, the effectiveness of the methods aimed to restore the static balance has been demonstrated by stabilometry data: COP sway areas reduced from 802.61 to 799.36 mm$^2$ ($p = 0.0034$) and the COP velocity decreased from 18.61 to 16.53 mm/s ($p = 0.414$) [4, 17]. Coordination training sessions led to higher Tinetti scores increased from 15.33 ± 0.65 to 19.69 ± 0.73 points ($p = 0.05$) [18]. At the same time, patients underwent adaptation kinesitherapy, which brought changes in EMG results: an unusual discoordination syndrome was registered, observed in poststroke motor disorders in the majority of muscles and manifested by the asymmetry of muscular activity during symmetrical movements [19]. Electroneuromyography data revealed an increase in the maximum amplitude of muscular response in *m. soleus* on the affected side from 399.9 ± 33.8 mV to 420.9 ± 37.7 mV, while *n. tibialis* motor response amplitude increased from 6.49 ± 0.25 mV to 6.69 ± 0.30 mV, associated with medical gymnastics [20].

The use of BalanceTutor for improving static and dynamic balance extends the potential of the rehabilitation treatment: BalanceTutor allows patients to do coordination exercises not only while standing, but also while walking, by stimulating a response to sudden postural perturbations of varying amplitudes. The values of stabilometric and functional parameters registered in the course of this study demonstrate that BalanceTutor-based rehabilitation is more effective than static balance training. BalanceTutor is a relatively new tool employed by Russian rehabilitation centers:  it was first used in our country in 2016. There have been no studies similar to this one conducted in Russia or abroad, which renders impossible the comparative analysis of data obtained from poststroke patients undergoing rehabilitation with BalanceTutor.

## CONCLUSIONS

The analysis of the obtained data allows considering the goal of the study achieved, which is confirmed by the objective examinations and scores from different assessment scales. Those poststroke patients who had undergone rehabilitation with BalanceTutor demonstrated a change at the paretic side of the body: the maximal muscle strain amplitude increased, mainly in the affected lower limb. Also, ENMG revealed an increase of the amplitude of motor response going through the peroneal nerve.

Improvement of the static balance and increased stability of poststroke patients find confirmation in the reduction of the COP sway area and COP velocity (mainly in the treatment group) with patients' eyes opened and closed. Lower Romberg ratios indicate a more active role of the proprioceptive system in retaining a vertical posture.

After the rehabilitation course, stability and gait of patients of the treatment group were found to correspond to mild impairments as measured by the Tinetti test. In the control group, these values remained within the limits describing moderate impairments.

The patients included in the treatment groups also had improved muscular strength and muscle tone scores, mainly in the lower limb of the paretic side. By the end of the course, there were almost twice as many mild paresis diagnoses (lower limb) in the treatment group as in the control group. Before the rehabilitation, the number of patients with mild to moderate degree of lower limb paresis was comparable in both groups. By the end of inpatient treatment, lower limb spasticity on the paretic side decreased almost 1.5 times in the treatment group in comparison with the controls.

This study demonstrates the effectiveness and feasibility of BalanceTutor as a component of the complex rehabilitation of poststroke patients with static and locomotor impairments.

### References


1. Gusarova SA, Styazhkina EM, Gurkina MV, Chesnikova EI, Sycheva AYu. [The new technologies of kinesiotherapy for the rehabilitation of the patients suffering from the post-stroke locomotor disorders]. Vopr Kurortol Fizioter Lech Fiz Kult. 2016 Mar–Apr; 93 (2): 4–8. Russian.
2. Daminov VD. Robotizirovannaya lokomotornaya terapiya v neyroreabilitatsii. Vestnik vosstanovitel'noy meditsiny. 2012; 47 (1): 54–9. Russian.
3. Razumov AN, Melnikova EA. [The modern approaches to the prognostication of rehabilitation of the patients after stroke on an individual basis: a review of the literature and the results of original investigations]. Vopr Kurortol Fizioter Lech Fiz Kult. 2015 Nov–Dec; 92 (6): 11–6. Russian.
4. Prokopenko SV, Ondar VS, Abros'kina MV. Sindrom tsentral'nogo gemipareza i narushenie ravnovesiya. Vestnik vosstanovitel'noy meditsiny. 2012; 51 (5): 23–8. Russian.
5. McCombe Waller S, Prettyman MG. Arm training in standing also improves postural control in participants with chronic stroke. Gait Posture. 2012 Jul; 36 (3): 419–24.
6. Mao Y, Chen P, Li L, Huang D. Virtual reality training improves balance function. Neural Regen Res. 2014 Sep 1; 9 (17): 1628–34.
7. Crenshaw JR, Kaufman KR. The intra-rater reliability and agreement of compensatory stepping thresholds of healthy subjects. Gait Posture. 2014 Feb; 39 (2): 810–5.
8. Inness EL, Mansfield A, Biasin L, Brunton K, Bayley M, McIlroy WE. Clinical implementation of a reactive balance control assessment in a sub-acute stroke patient population using a "lean-and-release" methodology. Gait Posture. 2015 Feb; 41 (2): 529–34.
9. Inness EL, Mansfield A, Lakhani B, Bayley M, McIlroy WE. Impaired reactive stepping among patients ready for discharge from inpatient stroke rehabilitation. Phys Ther. 2014 Dec; 94 (12): 1755–64.
10. Lakhani B, Mansfield A, Inness EL, McIlroy WE. Compensatory stepping responses in individuals with stroke: a pilot study. Physiother Theory Pract. 2011 May; 27 (4): 299–309.
11. Mansfield A, Inness EL, Lakhani B, McIlroy WE. Determinants of limb preference for initiating compensatory stepping poststroke. Arch Phys Med Rehabil. 2012 Jul; 93 (7): 1179–84.
12. Mansfield A, Inness EL, Wong JS, Fraser JE, McIlroy WE. Is impaired control of reactive stepping related to falls during

inpatient stroke rehabilitation? Neurorehabil Neural Repair. 2013 Jul–Aug; 27 (6): 526–33.
13. Sibley KM, Straus SE, Inness EL, Salbach NM, Jaglal SB. Balance assessment practices and use of standardized balance measures among Ontario physical therapists. Phys Ther. 2011 Nov; 91 (11): 1583–91.
14. Volovets SA, Sergeenko EYu, Darinskaya LYu, Yashinina YuA, Rubeykin IS, Zhitareva IV, et al. Metodika vosstanovleniya postural'nogo balansa u patsientov posle ostrogo narusheniya mozgovogo krovoobrashcheniya na osnove ispol'zovaniya sistemy dlya vosstanovleniya staticheskogo i dinamicheskogo ravnovesiya. In: Izbrannye voprosy neyroreabilitatsii [electronic edition]: Materialy IX mezhdunarodnogo kongressa «Neyroreabilitatsiya-2017»; 2017 Jun 1–2; Moscow, Russia. Moscow; 2017. p. 45–7; [cited 2017 Jun 30] Available from: http://congress-neuro.ru/sites/default/files/Materials_NR 2017.pdf Russian.
15. Volovets SA, Sergeenko EYu, Darinskaya LYu, Yashinina YuA, Rubeykin IS. Sposob reabilitatsii patsienta s narusheniem postural'nogo balansa. Russian patent application RU 2016138709. 2016 Sept 30. Russian.
16. Moscow Consensus on applying of stabilometry and biosteering for the footing reaction in practical health and research [Internet]. Moscow: P Kh Anokhin Science and research institute for normal physiology; c2017 [cited 2017 Jun 30]; 10 p. Available from: http://moscowstabilometryconsensus.ru Russian.
17. Shishkina ES, Beyn BN. [Persistence dynamics of patients who suffered from ishemic stroke in carotid and vertebrobasilar territories]. Medicinskij al'manah. 2014; 33 (3): 45–9. Russian.
18. Yastrebtseva IP. Patogenez formirovaniya narusheniy postural'nogo balansa pri insul'te i algoritm ikh korrektsii. In: Il'inskikh NN, editor. Fundamental'nye nauki i praktika: sbornik nauchnykh trudov. Tomsk: SSMU; 2010. 1 (4): 37. Russian.
19. Skvortsov DV, Bulatova MA, Kovrazhkina EA, Suvorov AIu, Ivanova GE, Skvortsova VI. [A complex study of the movement biomechanics in patients with post-stroke hemiparesis]. Zh Nevrol Psikhiatr Im S S Korsakova. 2012; 112 (6): 45–9. Russian.
20. Pelenitsyna EM. Elektromiograficheskie kriterii effektivnosti primeneniya razlichnykh metodov lechebnoy fizkul'tury u bol'nykh s tserebral'nym insul'tom [dissertation]. Moscow: RSMU; 2004. Russian.

**Литература**

1. Гусарова С. А., Стяжкина Е. М., Гуркина М. В., Чеснокова Е. И., Сычева А. Ю. Новые технологии кинезитерапии в реабилитации пациентов с постинсультными двигательными нарушениями. Вопр. курортол., физиотер. и леч. физ. культ. 2016; 93 (2): 4–8.
2. Даминов В. Д. Роботизированная локомоторная терапия в нейрореабилитации. Вестн. восстановит. мед. 2012; 47 (1): 54–9.
3. Разумов А. Н., Мельникова Е. А. Современные подходы к индивидуальному прогнозированию восстановления больных с инсультом в процессе реабилитации: обзор литературы и результаты собственного исследования. Вопр. курортол., физиотер. и леч. физ. культ. 2015; 92 (6): 11–6.
4. Прокопенко С. В., Ондар В. С., Аброськина М. В. Синдром центрального гемипареза и нарушение равновесия. Вестн. восстановит. мед. 2012; 51 (5): 23–8.
5. McCombe Waller S, Prettyman MG. Arm training in standing also improves postural control in participants with chronic stroke. Gait Posture. 2012 Jul; 36 (3): 419–24.
6. Mao Y, Chen P, Li L, Huang D. Virtual reality training improves balance function. Neural Regen Res. 2014 Sep 1; 9 (17): 1628–34.
7. Crenshaw JR, Kaufman KR. The intra-rater reliability and agreement of compensatory stepping thresholds of healthy subjects. Gait Posture. 2014 Feb; 39 (2): 810–5.
8. Inness EL, Mansfield A, Biasin L, Brunton K, Bayley M, McIlroy WE. Clinical implementation of a reactive balance control assessment in a sub-acute stroke patient population using a “lean-and-release” methodology. Gait Posture. 2015 Feb; 41 (2): 529–34.
9. Inness EL, Mansfield A, Lakhani B, Bayley M, McIlroy WE. Impaired reactive stepping among patients ready for discharge from inpatient stroke rehabilitation. Phys Ther. 2014 Dec; 94 (12): 1755–64.
10. Lakhani B, Mansfield A, Inness EL, McIlroy WE. Compensatory stepping responses in individuals with stroke: a pilot study. Physiother Theory Pract. 2011 May; 27 (4): 299–309.
11. Mansfield A, Inness EL, Lakhani B, McIlroy WE. Determinants of limb preference for initiating compensatory stepping poststroke. Arch Phys Med Rehabil. 2012 Jul; 93 (7): 1179–84.
12. Mansfield A, Inness EL, Wong JS, Fraser JE, McIlroy WE. Is impaired control of reactive stepping related to falls during inpatient stroke rehabilitation? Neurorehabil Neural Repair. 2013 Jul–Aug; 27 (6): 526–33.
13. Sibley KM, Straus SE, Inness EL, Salbach NM, Jaglal SB. Balance assessment practices and use of standardized balance measures among Ontario physical therapists. Phys Ther. 2011 Nov; 91 (11): 1583–91.
14. Воловец С. А., Сергеенко Е. Ю., Даринская Л. Ю., Яшинина Ю. А., Рубейкин И. С., Житарева И. В. и др. Методика восстановления постурального баланса у пациентов после острого нарушения мозгового кровообращения на основе использования системы для восстановления статического и динамического равновесия. В сб.: Избранные вопросы нейрореабилитации [электронная версия]: Материалы IX международного конгресса «Нейрореабилитация-2017»; 1–2 июня 2017 г.; Москва, Россия. М.; 2017. с. 45–7; [дата обращения: 30 июня 2017 г.] Доступно по: http://congress-neuro.ru/sites/default/files/Materials_NR2017.pdf
15. Воловец С. А., Сергеенко Е. Ю., Даринская Л. Ю., Яшинина Ю. А., Рубейкин И. С. Способ реабилитации пациента с нарушением постурального баланса. Заявка на патент на изобретение Российской Федерации RU 2016138709. 30 сентября 2016 г.
16. Московский консенсус по применению стабилометрии и биоуправления по опорной реакции в практическом здравоохранении и исследованиях [Интернет]. М.: НИИ нормальной физиологии имени П. К. Анохина; ©2017 [дата обращения: 30 июня 2017 г.]; 10 с. Доступно по: http://moscowstabilometryconsensus.ru
17. Шишкина Е. С., Бейн Б. Н. Динамика устойчивости пациентов, перенесших ишемический инсульт в каротидном и вертебрально-базилярном бассейнах. Мед. альманах. 2014; 33 (3): 45–9.
18. Ястребцева И. П. Патогенез формирования нарушений постурального баланса при инсульте и алгоритм их коррекции. В кн.: Ильинских Н. Н., редактор. Фундаментальные науки и практика: сборник научных трудов. Томск: СибГМУ; 2010. 1 (4): 37.
19. Скворцов Д. В., Булатова М. А., Ковражкина Е. А., Суворов А. Ю., Иванова Г. Е., Скворцова В. И. Комплексное исследование биомеханики движений у пациентов с постинсультными гемипарезами. Журн. неврол. и психиатр. 2012; 112 (6): 45–9.
20. Пеленицына Е. М. Электромиографические критерии эффективности применения различных методов лечебной физкультуры у больных с церебральным инсультом [диссертация]. М.: РГМУ; 2004.