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Research Article

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Dynamics of the Function of the Shoulder Joint and Shoulder Girdle Muscles in Patients with Hemiparesis during the Acute Stage of Hemispheric Stroke: A Randomised Trial

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Abstract

Question: How is dynamics of the function of the shoulder joint and shoulder girdle muscles in patients with hemiparesis during the acute stage compare to individual rehabilitation sessions (IRS) and IRS plus biofeedback (BF) training?

Design: Randomised, parallel-group trial with intention-to-treat analysis. Participants: Control group included 25 healthy persons. The group of 25 patients with hemiparesis during the acute stage of first-ever hemispheric stroke: a group receiving IRS (R group).

Intervention: The group of 25 the same type of patients: a group receiving along with IRS the BF training (R & BF group). Outcome measures: The study of patients was conducted before and after the individual set of rehabilitation measures: on the 3-5th day and after the course completion on the 21st day. Each of the participants passed a standard clinical examination and biomechanics investigation of kinematics of shoulders joints and trunk movement, and of EMG of girdle shoulders muscles.

Results: The control group recognized a normal pattern of kinematics of shoulders joints, trunk movements and EMG function. The results of the studies by the clinical scales did not show statistically significant differences in patients group. We noted decrease of all the basic amplitudes of the paretic limb and later EMG maximum activity. As a result of rehabilitation discovered a slight improvement of the paretic limb with somewhat better dynamics in the R & BF group.

Conclusion: Application of the combined technique of the rehabilitation treatment – rehabilitation with biofeedback – provides earlier activation of the reparative processes.

Keywords

Hemispheric stroke, Intention-to-treat analysis, EMG, Biofeedback, Kinematics

Introduction

Cerebral stroke is the second most frequent cause of mortality, according to the World Health Organization [1]. Approximately 95% of stroke survivors have an upper limb disorder of a various degree, which limits their everyday activity, muscle strength is a decrease, a disorder of coordination and friendly movements, a violation of voluntary and fine motor skills [2-4]. The acquired deficits lead to a persistent loss of working ability, alter the quality of life and affect the psychological and emotional state of patients and their loved ones [5, 6].

Selection of individual rehabilitation techniques during the acute stage of cerebral stroke plays an important role from the prognostic viewpoint, due to the fact that the initial arm weakness persists in 55%-75% of patients even after rehabilitation measures in the first three to six months [7]. Estimation of the physical rehabilitation efficiency is based on the analysis of the motor and functional abilities of a patient using clinical scales, various instrumental methods such as application of goniometers [8], techniques for the spatial motion analysis [9]. However, assessment of the short-term functional dynamics is rather difficult [10, 11].

Biomechanical studies of the shoulder joint function allow assessment of the existing pathology from the functional viewpoint [12-14]. The means of objective analysis for patients who survived cerebral stroke are of great importance for a physician [15]. Methods for analyzing kinematics of movements with synchronous registration of functional EMG allow you to get the necessary information about motor function and its pathological changes.

In general, the objective evaluation of the upper limb motions' biomechanics in patients after cerebral stroke is rather difficult, and studies on this subject are rarely found in the literature [16, 17]. No optimal technique which may be applied for patients during the acute stage has been suggested so far. The regularities of changes in the shoulder joint motor function in the process of medical rehabilitation are still unclear for patients with hemiparesis during the acute stage of hemispheric stroke [18, 19].

Therefore, the research questions for this study were:

1. To develop a methodology for objective examination of shoulder joint function, adapted for patients with hemiparesis during the acute period of hemispheric stroke.

2. Evaluate functional dynamics of shoulder joint after rehabilitation measures in acute period of hemispheric stroke by biomechanical and EMG parameters

3. Determine the most effective version of rehabilitation procedures for patients in acute hemispheric stroke

Materials and Methods

We involved three groups into the study (Table 1). Control group included persons without neurological or orthopedic pathology of the shoulder joint. Two basic groups included patients with hemiparesis during the acute stage of first-ever hemispheric stroke: a group receiving individual rehabilitation sessions (R group) and a group receiving individual rehabilitation sessions along with the BF training (R & BF group). For all the three groups, the right hand was dominating. The groups of stroke patients were comparable in terms of sex, age and neurological status. The distribution into groups was done at random. The study included patients with only primary stroke of the middle cerebral artery.

The general inclusion criteria for all subjects in the test and control groups were as follows: age under 75; functional readiness to verticalization; adequate response to a semi-orthostatic test; fully conscious and alert to understand and follow the study staff instructions during the study and exercise therapy; lack of cognitive impairment impeding the patient's ability to understand the tasks given by the investigator; lack of sensory and motor aphasia; shoulder muscle tone < 2 according to the Modified Ashfort Scale of muscle spasticity; absence of any decompensated somatic pathology, ischemic changes on the ECG, heart failure (Killip class II or higher); absence of any orthopedic pathology and traumatological history (joint deformities or contractures, severe pain syndrome, limb amputation, etc.). Inclusion criteria were based on data from disease histories, consultations with relevant specialists and functional samples.

Table 1: Characteristics of the studied groups.

Group	Number of patients	Male	Female	Mean age	Left hemi-sphere	Right hemi-sphere
Control	25	14	11	52.9 ± 11.0	-	-
R	25	12	13	62.8 ± 9.6	10	12
R & BF	25	14	11	63.6 ± 8.9	15	13

The study of patients in the basic groups with hemispheric stroke during the acute stage of the disease was conducted twice (before and after the individual set of rehabilitation measures): on the 3-5th day of treatment in the hospital and after the course completion on the 21st day.

Outcome measures: Each of the participants passed a primary examination before the study which included: muscle strength testing via the Medical Research Council Scale (1984), study of the limb motion deficit using the Motricity Index (1990) for the upper limb, study of the muscle tone by the Modified Ashworth Scale (1987), assessment of a patient's ability to self-care by the Barthel Index of Activities of Daily Living (1965), assessment of the functional readiness of patients – adequacy of their reaction to semi-orthostatic testing (The lying-to-sitting orthostatic test).

After the primary examination, all the participants underwent registration of the kinematic parameters of the shoulder joint function and trunk motions by a Trust-M system consists of inertial sensors which including two channels of EMG recording and wireless interface to computer (Figure 1). We registered EMG of the following muscles: frontal part of the deltoid muscle (FPDM), medial part of the deltoid muscle (MPDM), upper fragment of the medial part of the deltoid muscle (UMPDM). On average, it took 5-10 min for a patient with hemispheric stroke to complete the diagnostic exercise test. Patient's sitting on a stool, trunk not fixed. Makes movements in the shoulder joints - flexion-extension, abduction-adduction, up to 90 degrees, and external/internal rotation of the upper limbs. Motion kinematics was recorded in three mutually perpendicular planes according to the developed procedures [20]. Strap-down inertial sensors were used. The sensors were attached to the shoulder and the sternum with elastic cuffs (Figure 1). The initial position for test measurements was with the subject's arms hanging freely alongside the trunk.

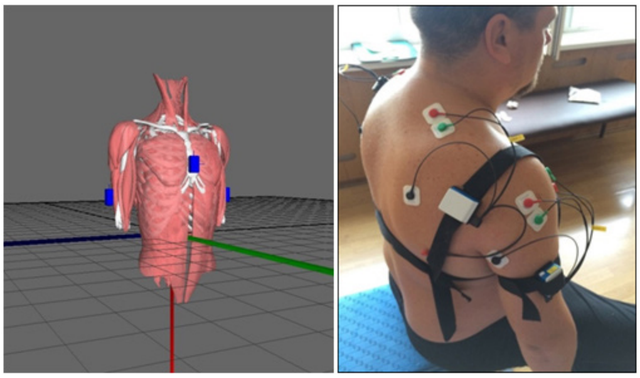

Figure 1: The biomechanics registration. On the left is 3D model, on the right is positioning of sensors on a patient.

We plotted an individual goniogram for each separate motion (flexion, abduction, rotation). The maximum amplitude «A» in degrees and the time of its appearance «T%» in % from the motion cycle were marked at the plots. We also plotted a profile of bioelectric activity of the performed motion for each EMG envelope. The maximum voluntary activity A (in μV) and the time at which it was reached, «T%» (in % from the motion cycle) were marked at the plot.

Intervention: In both groups rehabilitation sessions were performed starting on the 2nd or 3rd day from the stroke onset and to the 21st day (15 sessions in total). The second group additionally received training with BF of motions in the shoulder joint at the paretic side (10 BF sessions).

An individually developed program of medical rehabilitation was conducted for patients of both groups, which represented an optimal individual strategy of the shoulder joint function restoration under the continuous control over the cardiovascular system reaction to the physical exertion. The exercise therapy included physical exercises by systems: the ontogenetic kinesitherapy "Balance" (a successive, stage-by-stage pattern of assuming an upright position was restored); proprioceptive neuromuscular facilitation (PNF) (shoulder and pelvis diagonals, long diagonals of the upper and lower limbs on the paretic and contralateral sides, trunk movements lying, sitting) were used; Bobath therapy (moving, turns, on-bed activity, trunk and limb exercises while seated). The exercises were performed without pain.

The BF training was performed in front of a computer monitor. We utilized the same sensor as the one used for the motion study. The patient controlled a virtual object with shoulder motions in two planes: flexion-extension motion in the shoulder joint; abduction-adduction motion in the shoulder joint. The initial positions and the scale were adjusted individually. The training duration was 20-30 minutes, or up to the patient's tiredness.

Data analysis: The statistical processing of the results was performed via variation analysis using the STATISTIKA 6.0 software. The results were presented as Mean (M) ± standard deviation (s). The statistical significance of differences was estimated by the Student's t-test with $p < 0.05$ and lower.

Results

The initial indices of the patients groups did not show statistically significant differences. The results of the muscle strength testing are presented in the tables: Medical Research Council Scale (Table 2), Motricity Index (Table 3), Modified Ashworth Scale (Table 4), Barthel Index of Activities of Daily Living (Table 5). The results of the studies by the clinical scales did not show statistically significant differences in patients in the two basic groups, both for the primary examination and after the treatment complex ($p > 0.05$).

Table 2: Muscle strength in the proximal parts of paretic limbs in patients by the Medical Research Council Scale (points).

Test	Time	R group	R & BF group
Shoulder flexion	Before	2.92 ± 0.91	3.16 ± 0.99
	After	2.96 ± 0.84	3.32 ± 1.07
Shoulder abduction	Before	3.04 ± 0.98	3.24 ± 1.01
	After	3.24 ± 0.93	3.48 ± 1.08

Table 3: Degree of the motor deficit in the paretic upper limb by the Motricity Index (points) for the whole upper limb.

Time	R group	R & BF group
Before	52.88 ± 13.33	56.68 ± 15.04
After	54.56 ± 12.83	59.64 ± 17.39

Table 4: Muscle tone in the proximal parts of paretic limbs in patients by the Modified Ashworth Scale (points).

Test	Time	R group	R & BF group
Shoulder flexion	Before	0.84 ± 0.75	0.68 ± 0.69
	After	0.92 ± 0.76	0.64 ± 0.70
Shoulder abduction	Before	0.60 ± 0.65	0.52 ± 0.59
	After	0.56 ± 0.58	0.48 ± 0.59

Table 5: Barthel Index of activities of daily living in patients with hemispheric stroke depending on the localization of the motor deficit.

Time	R group	R & BF group
Before	68.33 ± 17.56	62.50 ± 18.48
After	71.67 ± 12.58	70.00 ± 15.00

Analysis of the kinematics data and functional electromyography of the control group demonstrated a number of general patterns. A simple motion in one plane has a basic component with the maximum amplitude in the plane of this motion and additional components in other planes with essentially lower amplitudes. The maximum of the EMG amplitude for muscles performing basic motions in a simultaneous motion of two arms and in each of the arms separately is higher than the additional components, while the time at which the maximum is reached occurs in the middle of the motion cycle ($p < 0.05$).

The trunk bending during the test motions occurs simultaneously in the three orthogonal planes. The moment of the maximum trunk shift takes place later than the maximum of the amplitude is reached for the basic arm motion.

The two arms flexion is characterized by statistically significantly lower amplitudes of the basic motion, reduced EMG activity of FPDM and MPDM, elevated activity of UMPDM and a statistically significantly wider auxiliary trunk motion, than those during flexion of each of the arms separately ($p < 0.05$). For abduction and rotation of each arm separately, the trunk shifts are characterized by a higher amplitude than that for the two arms simultaneously. The abduction motion of the two limbs levels the trunk, and no shifts take place. The right side is characterized by more active limb and wider auxiliary trunk motions ($p < 0.05$).

The EMG activity is symmetric both for the two arms motion and for each of the arms separately. The moment of the activity maximum approaches 50% of the motion cycle. For the "flexion-extension" and "abduction-adduction" motions the maximum activity is exhibited in the basic muscles responsible for the motion: FPDM and MPDM, respectively. In the rotation motion, we registered activity of the secondary (in respect to the basic motion) muscles. The bioelectric activity of the studied shoulder girdle muscles is symmetric in healthy subjects, both for the rotation of two arms and each arm separately.

Analysis of the kinematics data and functional electromyography of the patients' groups. We noted decrease of all the basic amplitudes of the paretic limb in all the tested motions. Arm flexion of both arms or only of the paretic arm before and after rehabilitation is characterized by reduction of the flexion and rotation amplitudes and by increase of the paretic limb abduction, as compared to the indices for the contralateral limb and for the control group ($p < 0.05$). The abduction motions are notable for decrease of the abduction and rotation amplitudes and increase of flexion of the paretic limb ($p < 0.05$).

In the process of rehabilitation measures in the basic groups we noted a slight improvement in the indices of the basic amplitudes of the paretic limb with somewhat better dynamics in the R & BF group in the conjugate and isolated motions of flexion and abduction (Figure 2). In the basic groups the time at which the maximum of the paretic limb flexion is reached before and after the treatment course does not statistically significantly differ from the indices of the control group ($p > 0.05$). Within the R group, the maximum amplitude of the paretic limb flexion is reached earlier during its isolated motion ($p < 0.05$) than it is reached during the two arms simultaneous flexion. The maximum amplitude of only the paretic limb flexion in the R group is reached earlier after the rehabilitation course, as well.

The time at which the maximum of the paretic limb abduction amplitude is reached in the basic groups does not statistically significantly differ from the indices of the control

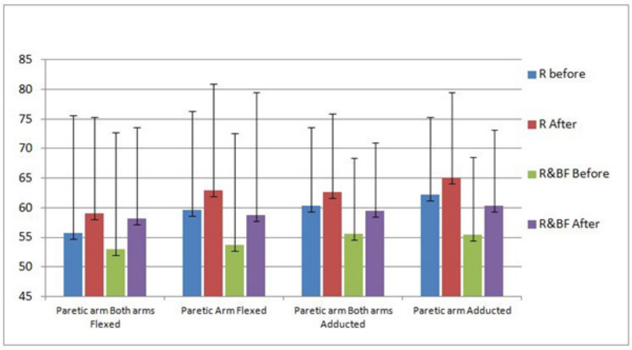

Figure 2: Dynamics of the basic amplitudes' (at degree) restoration in the paretic limb with standard deviation.

group ($p < 0.05$). The EMG activity of FPDM and MPDM is reduced at the paresis side as compared to the indices of the control group and of the contralateral limb ($p < 0.05$), and the moment at which the maximum appears is later than 50% of the motion cycle. In the process of rehabilitation measures we noted a relatively minor improvement of the EMG activity indices of FPDM and MPDM of the paretic limb (Figure 3) with a slightly better dynamics in the R & BF group in the conjugate and isolated motions of flexion and abduction. At the same time. no statistically significant differences in the indices before and after rehabilitation sessions were found ($p > 0.05$).

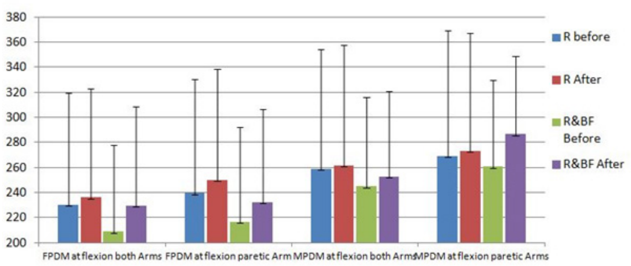

Figure 3: Bioelectrical activity at microVolts of the frontal and medial deltoid muscles with standard deviation.

The EMG maximum for FPDM and MPDM during the flexion and abduction motions before and after the rehabilitation measures is observed later than that for the contralateral limb and for the control group ($p < 0.05$).

After the rehabilitation complex, EMG maximum is detected earlier for FPDM and two arms flexion ($p < 0.05$), for MPDM and separate flexion and abduction ($p < 0.05$) which represents a positive dynamics.

After the R & BF complex, time of the maximum for FPDM during two arms flexion does not differ from that for the control group. The time of the EMG maximum for the paretic limb abduction after R & BF occurs earlier than that for the simultaneous arm abduction. paretic limb abduction before R & BF and the R group ($p < 0.05$). Such indices testify improvement of the EMG activity characterized by the shift of the maximum towards the normal value.

Compensatory trunk motions in the patients' groups are statistically significantly higher, while they are equal for both the subgroups. The flexion and abduction motions of both arms simultaneously and of the paretic arm separately are characterized by a greater amplitude of the trunk shift in the sagittal (backward bending), frontal (bending towards the contralateral shoulder) and horizontal (external rotation of the contralateral shoulder and internal rotation of the paretic shoulder) planes before and after the R and R & BF sessions, than those in the control group ($p < 0.05$).

For the paretic limb the time at which the maximum amplitudes of the trunk shift are reached is detected later than that for the limb itself, which is similar to the normal pattern. After the rehabilitation complex, we observed statistically significant decrease of the trunk shift amplitudes in the horizontal plane (X) during the contralateral limb abduction and in the frontal plane (Z) during the rotation of both arms simultaneously or the contralateral arm separately ($p < 0.05$), which demonstrated a functional improvement.

As a result of treatment course, we noted the following changes in the R & BF group: reduction of the trunk shifts in the sagittal plane in all the isolated test motions of the paretic limb and in the horizontal plane for the isolated rotation and abduction ($p < 0.05$); reduction of the trunk shift in the horizontal and frontal planes for the rotation of two arms simultaneously ($p < 0.05$).

Reduction of the amplitudes of the basic motions in the contralateral limb, as compared to those in the control group, were found in the R group for flexion of both arms and separate abduction, and in the R & BF group for isolated flexion and bilateral arm abduction ($p < 0.05$). The flexion amplitudes for the simultaneous abduction of both arms before and after rehabilitation and for only the paretic arm abduction after rehabilitation are statistically significantly greater than similar indices for the R & BF group ($p < 0.05$).

The EMG activity of FPDM during the isolated abduction motion of the paretic limb is statistically significantly lower in respect to the values for the control group and for the contralateral side and tends to decrease after the rehabilitation complex ($p < 0.05$), while during the simultaneous bilateral arm abduction it is statistically significantly lower than that for the contralateral limb and has a tendency to growth. The EMG activity of flexing FPDM is statistically significantly lower than that for the control group and for the contralateral limb during motion of both arms and the paretic arm separately and grows after the R & BF complex ($p < 0.05$).

The EMG activity of UMPDM during the simultaneous bilateral arm abduction is statistically significantly lower in the R & BF group than that in the R group. and the phase of its maximum activity takes place later and approaches 50% of the cycle, while it does not statistically significantly differ from the control group. This finding is obviously a result of the targeted BF training, since the “abduction-adduction” motions were actively used to control the virtual object.

The rotation motion in the shoulder joint is characterized by decrease of the rotation amplitude and increase of the additional amplitudes of abduction and flexion of the paretic limb as compared to the contralateral limb and to the control group ($p < 0.05$). This motion represents a deflection of the upper limb forward and sideways during rotation due to insufficient selectivity of the motion and weakness of the muscles performing the motion. This motion is strengthened by a corresponding bending backward and the trunk rotation towards the paretic side. The EMG analysis demonstrated the UMPDM maximum activity during rotation of two arms simultaneously and the paretic arm separately, before and after the R or R & BF sessions.

The EMG analysis has shown that. before and after the complex of rehabilitation measures, in the majority of cases the EMG amplitude maximum for activity of muscles performing the basic motions appears later than that in the control group and for the contralateral limb ($p < 0.05$). Improvement of the phase activity after the complex of rehabilitation measures, in the form of a shift of the cycle maximum towards 50%, occurs in the R group for FPDM during simultaneous bilateral arm flexion ($p < 0.05$), for MPDM - during separate flexion and abduction ($p < 0.05$). Improvements in the R & BF group are observed for FPDM during simultaneous bilateral arm flexion, for MPDM - during the paretic limb abduction. For MPDM the activity maximum during the paretic limb abduction appears earlier than that for simultaneous motion of both arms and for the paretic limb abduction before the R & BF and for the R group after the treatment ($p < 0.05$).

In the basic groups UMPDM demonstrates the maximum activity in rotation of both arms simultaneously before the rehabilitation measures, as compared to the value for the control group. Improvements occur mainly in the R & BF group after the treatment in the form of decrease of the EMG activity for the paretic limb FPDM and MPDM ($p < 0.05$), which testifies enhancement of the motion efficiency while the basic amplitude does not change.

Anomalous types of EMG activity with two maxima are found in 44% of patients for the flexion motion and in 22% of patients for the abduction motion. In patients with the anomalous EMG type, the first peak of activity appears before 50%, and the second peak is observed after 50% of the motion cycle. The number of patients demonstrating anomalous EMG types during the motion of two arms simultaneously is lower than that for only the paretic limb motion. This fact confirms the motor reciprocal influence, both of the affected side on the healthy side and vice versa. In the R group the frequency of this finding during the two arms flexion decreases by 12%, during the paretic limb flexion it decreases by 16%, during the two arms abduction it decreases by 4%, during the paretic limb abduction it decreases by 12%. In the R & BF group the frequency of this finding during the two arms flexion decreases by 12%, during the paretic limb flexion it decreases by 24%, during the two arms abduction it decreases by 12%, during the paretic limb abduction it decreases by 16%.

Discussion

The developed method of objective examination of amplitudes of movement and function of muscles of the shoulder joint in the position of sitting without fixation of the trunk, adapted for patients with hemiparesis in the acute period of hemispheric stroke, showed reliable results. We found the functional asymmetry in the groups under study, with the right side dominating. The obvious cause of asymmetry was the fact that all the participants were right-handed.

The obtained data demonstrate that the motions with the greatest amplitude always occur in the same plane with basic motion. The leading motion is performed by the upper limbs, they reach the maximum earlier, while for the trunk motion. The auxiliary motion is performed by the trunk. Thus, the functional insufficiency of a limb is compensated by the trunk motions, to a certain extent. Their probable influence is balancing, compensatory, leveling the position for center of gravity when the limbs' positions are shifted. It was found in the study [21].

For the motions of abduction-adduction and rotation we observed an opposite pattern: the amplitude is greater for an isolated one limb motion, which is confirmed by the balancing character of the trunk motions. A similar result was obtained in the study [22].

The additional components of the motion have rather small amplitudes in the normal state. In patients with paresis, the number of additional components is reduced – only basic component and one additional component are left. The third component is reduced to relatively small magnitudes. Similar data were obtained in the study [23].

The changes of the contralateral limb motions demonstrate the phenomenon of reciprocal two-way character influence between affected side and contralateral side. This is consistent with the earlier studies [24, 25].

Both in R and R & BF groups during the shoulder joint flexion a reduction in the amplitude of auxiliary abduction motion is detected after the treatment. This amplitude is initially statistically significantly higher than that for the contralateral limb and for the control group, while EMG of MPDM performing this motion does not statistically significantly differ from EMG of the control group and the contralateral side. The normal level of activity of this muscle with the reduced activity of the basic muscle is probably sufficient for the increase of the abduction motion. which is confirmed by the literature data [26].

The upper limb rotation motions were initially more difficult for the R & BF group patients than for the R group. The auxiliary motions of the trunk are notable for high amplitudes. It is the R & BF group where the improvement of the differentiation of the upper limb motions separately from the trunk has occurred. We attribute this finding to the results of the BF training.

The decrease of compensation at center of gravity shift due to trunk bending due to growth of muscle strength in the limb, enhancement of motor control of trunk and selectivity of motions in R & BF group.

We could assume that the kinematics study of motions combined with the EMG appears a highly informative technique for the diagnostics of the motor function deficits, as compared to the clinical scales. The shoulder joint motions in one plane contain a basic component with the maximum amplitude in the plane of this motion and additional components in other planes with essentially lower amplitudes and are accompanied by auxiliary trunk motions. The state of paresis at the shoulder joint level is functionally characterized by reduction of the basic motion amplitude and increase of one of the additional amplitudes. The amplitudes of the auxiliary trunk motions increasing at the same time. The typical abnormalities of the EMG activity are amplitude reduction and the maximum taking place later than that in the normal state. For the muscles performing the auxiliary function the EMG activity may reach the normal level.

The biomechanical techniques of the objective evaluation register the following functional changes: improvement of flexion (by 6% in the R group, by 10% in the R & BF group) and abduction (by 4% in the R group, by 9% in the R & BF group). At the same time, the maximum of the basic muscle activity for the given motion increases (by 2.5% in the R group, by 7.5% in the R & BF group) and shifts towards the values for the control group. During the shoulder joint rotation, we noted decrease of the EMG activity amplitude which testified that the EMG returned to normal, while the amplitude of the basic motions of the paretic limb increased.

Application of the combined technique of the rehabilitation treatment – rehabilitation with biofeedback – provides earlier activation of the reparative processes and more effective.

Ethics Approval

The Pirogov Russian National Research Medical University (RNRMU) Ethics Committee approved this study (№123 от 21.01.2013). Participants gave written informed consent before data collection began

Compliance with Ethical Standards

The study was approved by Local Ethics Committee of Pirogov Russian National Research Medical University (No. 123 dated 21.01.2013). Each subject signed a written informed consent after all potential risks and benefits, as well as the nature of the study had been explained to them.

Informed Consent

Each participant in the study submitted a voluntary written informed consent, signed by him after explaining to him the potential risks and benefits, as well as the nature of the forthcoming study.

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Conflict of Interest

The authors declare that there are no clear and potential conflicts of interest related to the publication of this article.

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