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RADIAL EXTRACORPOREAL SHOCK WAVE THERAPY DECREASES HAND SPASTICITY AFTER STROKE

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ABSTRACT

Introduction: Hand spasticity after a stroke reduces residual hand functions and decreases independence in everyday activities. It is a cause of pain, discomfort and one of the biggest obstacles encountered during the rehabilitation of patients with stroke consequences. Radial extracorporeal shock wave therapy (RESWT) is an enticing non-invasive treatment option for this medical problem.

Objectives: The main goal of this clinical study was to evaluate the effects of RESWT in the treatment of hand spasticity after a stroke.

Material and methods: This prospective controlled clinical study included 90 patients with post-stroke hand spasticity. At the beginning of the study, patients who met the inclusion criteria were divided into two groups: an examined group (EG) that received RESWT and a standard rehabilitation and a control group (CG) that received only a standard rehabilitation. In order to evaluate the efficiency of the treatment, the following clinical scales were used: Modified Ashworth Scale (MAS) and Disability Assessment Scale (DAS). Clinical findings were evaluated at the same time points in both groups of patients: before the start of the rehabilitation, immediately at the end of the 2nd, 6th and 14th week after the start of the rehabilitation (i.e., for the EG before the application of RESWT, immediately after the completion of RESWT, and at one and three months after the completion of RESWT).

Results: The results indicated a significantly lower MAS score in the EG.DAS results from the analysis of all domains (hygiene, dressing, hand position, pain) indicated a significant decrease in disability in the EG compared to the CG by more than one average score in all control time measurement points.

Conclusions: RESWT significantly reduced hand and fingers spasticity at the 2nd, 6th and 14th week following the start of the rehabilitation for more than one average MAS score ($p<0.05$). RESWT contributed to a significant decrease in disability of hygiene maintenance, dressing, hand position, and pain after the 2nd, 6th and 14th week of the start of the rehabilitation of post-stroke hand spasticity ($p<0.05$). No side effects were observed during and after application of RESWT. It is a safe, non-invasive therapeutic modality for hand spasticity after stroke.

Keywords: spasticity, stroke, radial extracorporeal shock wave therapy, rehabilitation

INTRODUCTION

Spasticity of the upper limbs after stroke is a common problem of millions of people worldwide. Prevalence rate ranges from 4% to 42%, and the incidence rate of disabling spasticity ranges between 2% and 13%. [1] Spasticity of the upper limbs occurs earlier and is of a more severe degree than that of the lower limbs; it is more pronounced in the hands and fingers. Early development of spasticity is associated with a difficult and slow motor recovery of the limb. [2, 3]

The concept of neural (reflex) and biomechanical (non-reflex) cause of spasticity is of great importance because therapeutic approaches are various. Neural hypertonia ("a motor disorder characterized by the velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, which results from hyper excitability of the stretch reflex, as one component of the upper motor neuron syndrome disorder"-Lance) can response to anti-spasticity medications, botulinum toxin injections. [4] On the other hand, biomechanical hypertonia (an increase in the number of myosin bridges between the myofilaments - shortening and contractures of the myocytes - Carey and Burghardt) does not respond to medical treatment. It is treated with rehabilitation procedures (stretching exercises, neurorehabilitation techniques, hydrokinesitherapy, manual massage, orthosis, motorized arm ergometer) and physical modalities (EMG biofeedback, vibration, neuromuscular electric stimulation, TENS, magnetic therapy). [4–7]

Radial extracorporeal shock wave therapy (RESWT) is a non-invasive therapeutic procedure that uses a high-intensity acoustic radiation.Radial shock waves are characterized by divergent pressure field, they are applied with an energy of 1-5Bars (0.15-0.47mJ/mm2), wavelength of 0.15 to 1.5 m, high peak pressure of 30 MPa, and penetration depth of 2–5 cm. In recent years, RESWT has actively attracted the attention as a possible treatment for spasticity reduction. [8, 9]

The aim of this study was to examine the effect of RESWT on spasticity and on hand disability after a stroke.

MATERIAL AND METHODS

This prospective controlled clinical study included 90 patients with post-stroke hand spasticity. All participants were fully informed about the trial, and each of them signed an informed consent form on voluntary participation.

Inclusion criteria: age between ≥18 and ≤80 years; a minimum of 3 months since an ischemic or hemorrhagic stroke; hand and fingers spasticity of the affected limb; use of unchanged dosage of anti-spasticity medicationsfor at least 3 months, and possible use of a passive forearm orthosis for at least 3 months. Exclusion criteria: use of anticoagulant therapy; previous/planned treatment with botulinum toxin, phenol, alcohol or surgical treatment; contracture in the hand and fingers of the affected extremity; and local inflammation at the area of application of the treatment.

Forty-five participants in the examined group (EG) were treated with RESWT and a standard rehabilitation program, while45 in the control group (CG) were treated only with a standard rehabilitation program.

The application of RESWT was conducted with BTL-5000 SWT Power Appliance (BTL Industries Ltd., United Kingdom). A total of six treatments were applied every two or three days over the spastic muscles: 1.500 shocks over m. flexor carpi radialis and m. flexor carpi ulnaris and 3,500 shocks on the muscles of the volar side of the hand, with an energy of 2Bars and a frequency of 10Hz. The application of the treatment started at the beginning of the rehabilitation.

The standard rehabilitation program for patients with hemiplegia after a stroke consisted of kinesitherapy, manual massage and occupational therapy.

The overall process of rehabilitation of both groups of patients lasted 4 weeks.

The efficiency of the treatment was evaluated with the Modified Ashworth Scale (MAS) and Disability Assessment Scale (DAS). The assessment of the spasticity of the wrist and fingers was performed with the MAS. For convenience of the statistical analysis, MAS grade 1+ was point

2; grades 2, 3, and 4 were respectively matched to 3, 4, and 5.

DAS evaluates upper extremity functional disability in patients with stroke spasticity in 4 domains (hygiene, dressing, limb position, and pain). Extent of palm maceration, ulceration or infection are evaluated for the hygiene domain-cleanliness of the palm, easy of cleaning, nail trimming; effect of hygiene-related disability on other areas of functioning. Ability to dress is evaluated for the dressing domain-effect of dressing-related disability on other areas of functioning. For the limb position domain, psychological or social obstacles that the limb positioning creates in a patient's life are evaluated. For the pain domain, intensity of pain or discomfort related to upper-limb spasticity is evaluated-interference with activities of daily living. Each item is evaluated on a scale from 0-3, where: 0= no disability, 1= mild disability (noticeable but does not interfere significantly with the normal activities), 2= moderate disability (normal activities require increased effort and/or assistance), 3= severe disability (normal activities are limited).

Clinical findings were evaluated at the same time points for both groups: before the start of the rehabilitation, immediately after the completion of the second, sixth and fourteenth week of the rehabilitation (for the examined group before the RESWT application, immediately after the completion of the RESWT application, immediately after the first and the third month upon completion of the RESWT application).

RESULTS

Statistical analysis of data was made by means of the statistical package SPSS 20.0. All statistically significant differences were discussed at asignificance level of $p<0.05$.

The mean age of patients in the study was 56/9±11.1 years. For $p>0.05$, there was no significant difference between the two groups regarding patients' age (Mann-Whitney U Test: Z=-0.9038; p=0.3661)and sex (Pearson Chi-square=0.4008; df=1; p=0.5267).

The analysis showed that the average time from the onset of stroke to hospital admission of all patients was 15.99±14.8 months. For $p>0.05$, no significant difference was observed between the two groups regarding time from the onset of stroke to admission (Mann-Whitney U Test: Z=1.6946; p=0.0901).

Of the total 90 patients included in the study, 68 (75.6%) had ischemic stroke and 22 (24.4%) had hemorrhagic stroke. For $p>0.05$, the analysis of all patients showed no statistically sig-

Table 1. *Comparison of MAS scores at four-time measurement points by groups*

Measurement time	Number (N)	Mean	Standard deviation Std. Deviation	Minimum (Min)	Maximum (Max)	Percentiles		
						25th	50th (Median)	75th
EG - Friedman test: Chi-Square (3)=113.452; p=0.0001*								
Admission	45	3.51	0.99	2	5	3	4	4
2 week	45	2.09	1.22	0	4	1	2	3
6 week	45	2.09	1.18	0	4	1	2	3
14 week	45	2.36	1.15	1	4	1	3	3
CG - Friedman test: Chi-Square (3)=13.393; p=0.004*								
Admission	45	3.31	1.02	2	5	2	3	4
2 week	45	3.13	1.12	1	5	2	3	4
6 week	45	3.22	1.06	1	5	2	3	4
14 week	45	3.36	1.01	2	5	2.5	3	4

*significant for $p<0.05$**2ndweek= control 1; 6thweek= control 2; 14thweek= control 3 nificant association between the groups and the type of the stroke (Pearson Chi-square=0.2406; df=1; p=0.6237).

The analysis by groups demonstrated a statistically significant difference in the spasticity of the wrist and fingers from the start of the rehabilitation program in the EG (Fridman test: Chi-Square (3)=113.452; p=0.0001)as well as in the CG (Fridman test: Chi-Square (3)=13.393; p=0.004) (Table 1).

A comparison was made between the EG and CG based on MAS scores at four-time measurement points (Table 2).

The comparison showed a significant difference at all three control time-points of measurement in favor of a significantly lower MAS score in the EG. The comparison between the two groups with regard to MAS scores showed a significant difference at control time points of measurements, as follows: a) control 1 (Mann-Whitney U Test: Z=-3.559; p=0.0004); b) control 2 (Mann-Whitney U Test: Z=-4.059; p=0.00005); andc) control 3 (Mann-Whitney U Test: Z=-3.657; p=0.0003, favoring everywhere a significantly lower MAS score in the EG (Table 2). For p>0.05, the analysis revealed no significant difference between the two groups regarding the MAS score on admission.

A statistically significant difference was observed in the impairmentofhygiene maintenance in patients with hand spasticity from the start of the rehabilitation program (Table 3).

The comparison between the two groups with regard to disability to maintain hygiene among patients with hand spasticity after stroke showed a significant difference at three measurement time points, as follows: a) control 1(Mann-Whitney U Test: Z=-3.748; p=0.0002); b) control 2(Mann-Whitney U Test: Z=-3.716; p=0.0002); and c) control 3(Mann-Whitney U

Table 2. *Comparison of MAS scores between the groups at four-time points*

Mann-Whitney U test	Admission	Control 1	Control 2	Control 3
Z	(0.928)	(-3.559)	(-4.059)	(-3.657)
Asymp. Sig. (2-tailed)	0.353	0.0004*	0.00005*	0.0003*

* significant for p<0.05** group variable: examined/control

Table 3. *Comparison of disability inhygienemaintenance at four-time points by groups*

Measurement time	Number (N)	Mean	Standard deviation Std. Deviation	Minimum (Min)	Maximum (Max)	Percentiles		
						25th	50th (Median)	75th
Examined group - Friedman test: Chi-Square (3)=116.331; p=0.000001*								
Admission	45	2.00	0.64	1	3	2	2	2
2week	45	0.91	0.67	0	2	0	1	1
6week	45	0.87	0.73	0	2	0	1	1
14week	45	0.91	0.73	0	2	0	1	1
Control group - Friedman test: Chi-Square (3)=24.579; p=0.0001*								
Admission	45	1.89	0.68	1	3	1	2	2
2week	45	1.64	0.83	0	3	1	2	2
6week	45	1.60	0.81	0	3	1	1	2
14week	45	1.82	0.72	1	3	1	2	2

*significant for p<0.05**2ndweek= control 1; 6thweek= control 2; 14thweek= control 3

Test: Z=-4.676; 0.000003). At all three control time points, the disability to maintain hygiene was significantly lower in the EG than in the CG. For p>0.05, the analysis showed no significant difference between the two groups regarding hygiene maintenance disability upon admission (Mann-Whitney U Test: Z=0.726; p=0.468).

During this examination, an analysis was conducted on the disability of both groups of patients to dress themselves at four points in time. The analysis of the EG showed a statistically significant difference in the disability to dress from the start of the rehabilitation program (Friedman test: Chi-Square (3)=120.097; p=0.0001), whereas no significant difference was found in the CG (Friedman test: Chi-Square (3)=5.182; p=0.1591).

The comparison between both groups of patients with post-stroke hand spasticity treated with different treatment procedures regarding the disability to dress themselves showed a significant difference at three control measurement time points, as follows: a) control 1(Mann-Whitney U Test: Z=-5.197; p=0.000001); b) control 2(Mann-Whitney U Test: Z=-5.334; p=0.000001); and c) control 3(Mann-Whitney U Test: Z=-5.237; 0.000001). At all three time points, the disability of the EG patients to dress was significantly lower compared to the CG. For p<0.05, no significant difference between the two groups was detected in terms of disability to dress upon admission (Mann-Whitney U Test: Z=0.141; p=0.888) (Table 4).

The comparison between the two groups regarding disability due to hand position demonstrated a significant difference at three time points, as follows: a) control 1(Mann-Whitney U Test: Z=-5.536; p=0.000001); b) control 2(Mann-Whitney U Test: Z=-5.863; p=0.000001); and c) control 3(Mann-Whitney U Test: Z=-5.463; 0.000001). At all three control time points, the disability of the EG patients due to hand position was significantly lower compared to the CG. For p>0.05,the analysis revealed no significant difference between the two groups in terms of the disability due to hand position on admission (Mann-Whitney U Test: Z=-0.206; p=0.837).

The analysis between the EG and CG detected a statistically significant difference regarding disability due to pain since the start of the rehabilitation treatment. The analysisof the EG showed a statistically significant difference in the disability due to pain since the start of the rehabilitation treatment (Friedman test: Chi-Square (3)=121.69; p=0.0001) (Table 5).

The comparison between the two groups with regard to disability due to pain displayed a significantly lower disability in the EG than in CG at all three control time points. For p>0.05, no significant difference was found between the two groups regarding the disability due to pain upon admission.

DISCUSSION

Hand spasticity is one of the most common issues encountered during the rehabilitation of a plegic upper limb after stroke.

The duration of rehabilitation after a stroke is three times longer in patients with spasticity than in those without it. Among patients with motor dysfunction of the upper limb, up to 40% develop spasticity after stroke. [5]

Spasticity is associated with muscle weakness, reduced range of motion, contractures of the hand and fingers, pain when an individual is attempting to dress himself and stretch the hand, common infections of the hand and fingers due to ingrown nails, and skin maceration between the fingers. In addition, hand spasticity leads to the disability to perform daily activities, such

Table 4. *Comparison of disability to dress between the groups at four time points*

Mann-Whitney U test	Admission	Control 1	Control 2	Control 3
Z	(0.141)	(-5.197)	(-5.334)	(-5.237)
Asymp. Sig. (2-tailed)	0.888	0.00000*	0.00000*	0.00000*

*significant forp<0.05** group variable: examined/control***control 1=2ndweek; control2=6thweek; control 3=14thweek

Table 5. *Comparison of the disability due to pain at four time points by groups*

Measurement time	Number (N)	Mean	Standard deviation Std. Deviation	Minimum (Min)	Maximum (Max)	Percentiles		
						25th	50th (Median)	75th
Examined group - Friedman test: Chi-Square (3)=121.690; p=0.0001*								
Admission	45	1.53	0.76	0	3	1	1	2
2week	45	0.24	0.48	0	2	0	0	0
6week	45	0.27	0.49	0	2	0	0	0.5
14week	45	0.27	0.49	0	2	0	0	0.5
Control group - Friedman test: Chi-Square (3)=17.757; p=0.0001*								
Admission	45	1.84	0.85	0	3	1	2	3
2week	45	1.60	0.91	0	3	1	1	2
6week	45	1.67	0.93	0	3	1	2	2
14week	45	1.73	0.91	0	3	1	2	2

*significant for p<0.05
**2ndweek= control 1; 6thweek= control 2; 14thweek= control 3

as difficulty in eating, dressing, maintaining hygiene, bed transfer, or driving a wheelchair.

Patients seek the greatest benefit from spasticity reduction in direction of decreased disability, better quality of life, and greater independence in daily activities.

All patients in our study were monitored throughout the entire period. Patients from both groups were with chronic hemiplegia.

The primary aim of this study was to examine the effect of RESWT on hand spasticity after stroke. The average MAS score in the EG was highest on admission, and lowest after completion of RESWT application and one month following RESWT. Three months after RESWT, the MAS assessment showed an increase, but it was still significantly lower compared to that on admission. The analysis of the EG showed a statistically significant reduction in hand spasticity. The comparison between the two groups regarding MAS scores revealed a significant difference at all control time points favoring every where a significantly lower MAS score in the EG. In our study, there was reduction in the average MAS score in the EG for at least one score at each subsequent control, which was a huge therapeutic and clinical success.

Our results have demonstrated that a one-month standard rehabilitation program combined with RESWT in comparison with a one-month standard rehabilitation program results in a significantly greater and long-term (longer than 12 weeks) reduction in spasticity after stroke. These results align with findings from other studies that have used RESWT in the treatment of upper limb spasticity after stroke. [10–14]

The Disability Assessment Scale is a highly sensitive tool for the evaluation of functional disability in patients with upper limb spasticity after stroke. It is characterized by good intra-rater and inter-rater reliability, and is easily applicable in clinical conditions. [15–17]

The analysis of the obtained results across all domains (hygiene, dressing, hand position, pain) on the DAS indicated that the group of patients who received a combination of the standard rehabilitation program and RESWT had a significant reduction in disability for at least one average grade in comparison with the CG at all control time points of measurement. This is a significant success for RESWT as a non-invasive antispastic therapeutic approach.

The long-term positive effects of RESWT in synergy with other therapies (kinesitherapy, mirror therapy, occupational therapy, physical modalities, botulinum toxin, application of passive forearm orthosis) have been proved. [18–21]

ESWT is an effective adjuvant treatment to increase the effectiveness of botulinum toxin treatment for post-stroke spasticity. [22]

Botulinum toxin is widely used in efforts to reduce focal spasticity of the hand after stroke.

However, its effectiveness is commonly influenced by several factors (neutralizing antibodies, improper product handling, inappropriate dosing and technique of injection, temporary effect, interval of at least 3 months between applications, financial burden). [23–25]

Electromyographical clinical studies have proved that increased muscle tone caused by the increased reflex activity reaches its maximum between 1 to 3 months post-stroke. [26] After 3 months, the increase in resistance to passive stretching is largely due to intrinsic muscle changes (reduced number of sarcomeres, abnormal thixotropy and changes in the extracellular matrix, increased intramuscular connective tissue, increased amount of fat tissue, and degenerative changes in muscle-tendon units). [2, 6, 7, 27–32]

Thus, the effectiveness of botulinum toxin in improving motor function is controversial; in cases where there is anextensive fibrous tissue even high units of toxin, cannot reduced the hypertonia. [30]

Why the reduction in hypertonia occurs after RESWT application has not yet been fully elucidated. It is believed that shock waves cause the synthesis of nitric oxide (NO), which, in turn, induces modulationin neurotransmission at the level of neuromuscular synapse, memory, and synaptic plasticity in the central nervous system as well as production of new neuromuscular synapses in the peripheral nervous system. [33–36]

In comparison with the normal muscle fibers, spastic fibers are richer in connective elements due to shorter sarcomeres, which means a dramatic remodeling of intracellular and extracellular structural components such as titan and collagen. Reduced or impossible activation of the motor units of the spastic muscles leads to inactivity hypotrophy, an increased amount of collagen fibers, and increased intrinsic stiffness contributing to muscle shortening, immobilization of the affected joint, and contracture.

It is assumed that shock waves enhance the rheological properties of hypertonic muscles and havea direct effect on the non-reflex biomechanical component. By stimulating NO synthesis, vasodilation, angiogenesis, modulation of secretion of interleukins, and activation of the growth factor occur. This, in turn, influences on the increase in the number of sarcomeres and subsequent extension of muscle length. Another important aspect of RESWT is by its mechanobiological effect to synthesize pro- and anti-fibrotic proteins (TGF-beta1 and matrix metalloproteinase-2), thereby inducing remodeling and resorption of fibrotic tissue in spastic muscles. [36, 37]

The potential direct thixotropic effect of shock waves on muscle tissue should also be taken into consideration. Carey and Burghardt suggest that adaptation and increase in the number of connecting bridges between actin and myosin filaments occurs in spastic muscles, leading to abnormal stiffness. It is thought that this stiffness is a result of the insufficient rapid release of myosin bridges from actin after contraction, which agrees with findings about the prolonged contraction of spastic muscles. [7, 27] Also, it is assumed that theshock waves of RESWT break and help in separating these functional links between actin and myosin, thereby reducing the existing stiffness in chronically spastic muscles not influencing on neurophysiological mechanisms. [34]

Spastic muscles have reduced extensibility due to alterations in the soft tissue of the muscle, which results in increased excitability of the muscle spindle fibers, and consequently more pronounced spasticity. By reducing fibrosis and improving the soft tissue properties in spastic muscles, extensibility is improved, excitability of muscle spindle is decreased, and hypertonia is reduced. Biomechanical evaluation of spasticity (which is the most reliable indicator) confirms the positive effects of RESWT. Results indicate that the anti-spastic effects of RESWT are primarily due to changes in the biomechanical properties of muscles rather than to alterations in the neural reflex component of spasticity. [38, 39]

The necessity of new non-invasive treatments for hand spasticity after stroke is essential, as hand spasticity after stroke is difficult to manage with medication therapy. The remaining options for local antispastic treatment are often inconvenient, poorly tolerated, and limited in application.

An optimal protocol for the application of RESWT should be established in the future.

CONCLUSIONS

RESWT significantly reduced spasticity of hand and fingers after stroke at the 2nd, 6th and 14th weeks following initiation of rehabilitation for more than one average MAS score (p<0.05). RESWT contributes to a significant reduction in disability related to hygiene maintenance, dressing, hand positioning, and pain after 2, 6, and 14 weeks of treatment of post-stroke hand spasticity (p<0.05). No side effects were observed during and after RESWT application. It is a safe, non-invasive therapeutic modality of managing hand spasticity after stroke.

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Резиме

РАДИЈАЛНАТА ЕКСТРАКОРПОРАЛНА ТЕРАПИЈА СО УДАРНИ БРАНОВИ ГО НАМАЛУВА СПАСТИЦИТЕТОТ НА РАКАТА ПО МОЗОЧЕН УДАР

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Вовед: Спастичната рака по мозочен удар ги намалува преостанатите функции на раката и ја намалува независноста во секојдневните активности. Таа е причина за болка, дискомфор и една од најголемите пречки со кои се соочуваат пациентите со последици од мозочен удар. Радијалната екстракорпорална терапија со ударни бранови (РЕКТУБ) е привлечна неинвазивна можност за третман на овој медицински проблем.

Цели: Главната цел на оваа клиничка студија беше да се проценат ефектите на РЕКТУБ во третманот на спастична рака по мозочен удар.

Материјал и методи: Оваа проспективна контролирана клиничка студија вклучуваше 90 пациенти со спастична рака по мозочен удар. На почетокот на студијата пациентите што ги исполнуваа критериумите за вклучување беа поделени во две групи: испитувана група (ИГ), која прими РЕКТУБ и стандарден третман за рехабилитација и контролна група (КГ), која прими само стандарден третман за рехабилитација. За да се процени ефикасноста на третманот, беа користени следните клинички скали: Модифицирана скала Ашфорт (МАС) и Скала за процена на онеспособеноста. Клиничките наоди беа оценети во исти временски точки кај двете групи пациенти: пред почетокот на рехабилитацијата, веднаш по завршување на 2-рата, 6-тата и 14-тата недела од почетокот на рехабилитацијата (т. е. за ИГ пред примената на РЕКТУБ, веднаш по завршувањето на РЕКТУБ и еден и три месеци по завршувањето на РЕКТУБ).

Резултати: Резултатите покажаа значително понизок МАС-скор во ИГ. Резултатите од анализата на сите домени од Скалата за процена на онеспосбеноста (хигиена, облекување, положба на раката, болка) покажаа значително намалување на онеспособеноста во ИГ во споредба со КГ за повеќе од една просечна оценка во сите контролни точки на мерење.

Заклучоци: РЕКТУБ значително ја намали спастичноста на раката и прстите по 2-рата, 6-тата и 14-тата недела од почетокот на рехабилитацијата за повеќе од еден просечен МАС-скор ($< 0,05$). РЕКТУБ придонесе за значително намалување на онеспсобеноста за одржување на хигиената, облекувањето, положбата на раката и болката по 2-рата, 6-тата и 14-тата недела од почетокот на рехабилитацијата ($p < 0,05$). Не се забележани несакани ефекти за време на примената на РЕКТУБ и потоа. Таа е безбеден, неинвазивен терапевтски модалитет за спастична рака по мозочен удар.

Клучни зборови: спастицитет, мозочен удар, радијалната екстракорпорална терапија со ударни бранови, рехабилитација