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# Electromyographic Control of Botulinum Toxin A Injections in the Upper Limb Muscles in Patients with Spasticity of Various Etiologies

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**Aim.** The study aim was to investigate the efficacy of botulinum toxin A injections under EMG control in patients with upper limb spasticity of various etiology for decreasing muscle tone and improving the passive limb function as well as to assess the possibility of a botulinum toxin dose reduction under combination of these techniques. **Material and methods.** Sixty one patients with upper limb spasticity of various etiologies were evaluated. All patients underwent treatment at the Rehabilitation Department of the Burdenko Neurosurgical Institute in the period between 2009 and 2014. The main group consisted of 29 patients administered the abobotulinum toxin A (botulinum toxin type A (BTXA), 500 U per vial) under EMG control. The control group consisted of 32 patients administered BTXA without EMG control. A repeated BTXA injection was performed on the 4th month of the study. Patients in both groups received standard rehabilitation therapy. The spasticity pattern was determined using the Arm Spasticity Pattern (ASP) scale. Evaluation of the treatment efficacy was performed using the modified Ashworth scale (upper limb spasticity evaluation), modified Barthel Index scale (life quality evaluation), Disability Assessment Scale (DAS), and Clinical Global Impression (CGI) scale. **Results.** The main spasticity patterns in patients of the main and control groups were as follows: the type III pattern was in 13 (44.8%) and 17 (53.1%) patients, respectively; the type I pattern was in 9 (31.0%) and 9 (28.1%) patients, respectively; the type VI pattern occurred in 7 (24.2%) and 6 (18.8%) patients, respectively. A significant improvement was observed in both groups one month after the BTXA treatment start. However, the improvement in the main group was more pronounced compared to that in the control group ($p<0.05$). This difference persisted throughout the whole treatment period ($p<0.05$). The DAS score demonstrated an improvement in both groups, but only patients of the main group had a statistically significant improvement in putting the arm through a sleeve ($p<0.05$). The use of EMG control reduced an administered BTXA dose by 50—300 U. Conclusions. BTXA injections under EMG control in upper limb spasticity patients may improve the treatment efficacy.

***Keywords:*** *upper limb spasticity, botulinum toxin, electromyography.*

Spasticity is a motor disorder being a symptom of the upper (located in the cerebral cortex) motor neuron syndrome. Spasticity is characterized by a velocity-dependent increase in the stretch reflex (muscle tone) and is accompanied by an increase in tendon reflexes, resulting from hyperexcitability of stretch receptors [1].

Spasticity is one of the most disabling consequences of many neurological diseases, including acute cerebrovascular accident (ACVA), traumatic brain injury (TBI), brain tumors, etc. [2, 3]. Spasticity significantly reduces patients' quality of life, is often accompanied by pain, and can cause restriction of limb movements, damage to the skin, and self-care problems. In the long-term period, spasticity may lead to fixed contractures, which significantly limits the capabilities of rehabilitation of these patients, complicates care for them, and ultimately increases the cost of treatment.

Spasticity developing in the upper limb is the most deconditioning and poorly treatable symptom. In recent years, traditional physiotherapeutic approaches to the treatment of spasticity have been supplemented by a variety of methods, including injections of the botulinum toxin type A (BTXA) that has demonstrated its safety and efficacy in reducing muscle tone in focal spasticity of the upper limb after stroke and injury and in improving the passive upper limb function [4, 5]. The data of recent studies [1, 4] indicate also a possible efficacy of botulinum toxin therapy in improving the active upper limb function.

In recent years, special attention has been paid to the botulinum toxin injection accuracy. For this purpose, a variety of injection visualization and control techniques have been used: ultrasound, electromyography (EMG), electrical stimulation (ES), and, in some cases, computed tomography (CT). However, there is now no consensus on the most effective injection technique [6]. A number of studies have demonstrated that relying on the anatomical landmarks only for making injections is not sufficient, while the use of ultrasound, ES, and EMG control improves the injection accuracy and, most importantly, treatment efficacy.

Botulinum toxin injection control using electromyography helps a doctor-injector and is recommended for injections into small and hard-to-reach muscles of the upper limb, in challenging situations, in the presence of co-contraction symptom, as well as in cases of an insufficient efficacy of previous injections. EMG control is implemented by means of either classic needle electromyography or Synapsis MIST portable electromyographs; the latter are particularly convenient for the routine daily use, do not require special long-term training, and are equipped with special needles for botulinum toxin introduction. This device transmits the

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bioelectrical activity of muscles to headphones or portable speakers. Using the specific myogram audio parameters (characteristic noise of the end plates in the presence of spontaneous locomotor activity), the doctor can correctly verify the injection site (the louder sound is associated with the site of the greatest motor plaque accumulation), which gives an indication of an indirect muscle activity (passive monitoring). If necessary, a stimulation mode, which is available in the device, can be selected for stimulating the muscle to ensure, active monitoring [6, 7], accurate identification of an affected area of the target muscle [8].

The accuracy of a drug injection into the muscle selected based on clinical indications is an important aspect of botulinum toxin therapy. Therefore, it is important to know exactly the topographical features of muscles forming a particular abnormal patter and to determine the optimal injection sites, number of points, and the drug dose for each muscle.

There are several upper limb spasticity patterns (**Table 1**). The most common 5 types of the upper limb patterns are as follows: type I — an adducted and internally rotated shoulder; type II — a flexed elbow; type III — a flexed wrist; type IV — a pronated forearm; type V — a clenched fist.

In addition, three forms of hand spasticity are distinguished: 1) a spastic flexed hand; 2) a claw-shaped hand; 3) an internal worm-like hand [9—11].

Each of the patterns is formed by several muscles.

For example, the flexed elbow pattern is formed by 3 muscles: *m. biceps brachii, m. brachialis,* and *m. brachioradialis,* which are synergists; however, the key (most spastic) muscles among them can be only the first or second muscle, and therefore, they are injected. In addition, a contribution of antagonist muscles *(m. triceps brachii* in this pattern) to the pattern formation can not be ignored. The muscle activity enables implementation of an EMG examination conducted during the injection. To date, there is no unified approach to the choice of muscles, number of injection sites, and injection control method. Some doctors perform an intramuscular injection using a single site, while other doctors use several different sites, keeping in the mind that drug diffusion from the injection site amounts to 2—3 cm, and denervation of a large muscle belly requires drug injection at several sites, especially in the case of large muscles, e.g., *m. biceps brachii,* where each muscle belly is injected at two sites.

The most common injected muscles are as follows: *m. pectoralis major, m. biceps brachii, m. brachialis, m. brachioradialis, m. extensor carpi ulnaris, m. flexor carpi radialis, m. flexor carpi ulnaris, m. flexor digitorum superficialis, and m. flexor digitorum profundus.* There is also a certain variation in drug doses for each muscle.

For example, doses can vary for the same muscle, depending on the spasticity degree. However, the European consensus on botulinum toxin therapy [12] recommends 125 U as the maximum and safe drug dose for an injection into one site and 1,000 U as the total drug dose for one injection into the whole upper limb.

It should also be noted that not every spasticity pattern requires botulinum toxin therapy. In this regard, setting personalized and realistic goals for each patient before treatment is an very important task.

Currently, an algorithm for botulinum toxin therapy of spasticity has been suggested [13].

1. *Setting goals* that should be specific, measurable, achievable, realistic, and time-specific **(SMART principle).**

2. *Muscle selection.*

3. *Injection accuracy* (use of EMG, ultrasound, or ES).

4. *Combining specific physical treatments with botulinum toxin injections.*

In recent years, a considerable number of international papers on the injection accuracy problem have been published, while the number of Russian publications on this subject is small. And the question still remains open: whether BTXA injections under EMG control are able to lead to better functional outcomes and to improve the efficacy of treatment of patients with upper limb spasticity. The question requires further research [14, 15].

The study aim was to investigate the efficacy of combined use of botulinum toxin type A injections and EMG control using a MIST portable device in patients with upper limb spasticity of various etiologies in order to reduce muscle tone and improve the passive limb function as well as to determine the possibility of reducing a botulinum toxin dose under combination of these methods.

## Material and Methods

The study included 61 patients aged from 34 to 68 years with upper limb spasticity due to ACVA, TBI, or brain tumor (**Table 2**). All patients were treated at the Rehabilitation Department of the Burdenko Neurosurgical Institute in the period between 2009 through 2014.

The inclusion criteria were as follows: absence of earlier BTXA injections; patients' age of 18 to 70 years; spasticity severity of more than 2 points on the modified Ashworth scale [16]; no infectious disease within 1 month before study enrollment; no surgical interventions on the involved muscle in the medical history; spasticity duration from 0.5 to 1.5 years.

The patients were divided into two groups: the main group where EMG control was used during botulinum toxin injections; the control group where injections were performed relaying on the anatomical landmarks only.

In the main group, an injection of BTXA (abobotulinum toxin type A, botulinum toxin type A, 500 U per vial) was performed under EMG control by a MIST

***Table 1.*** **Patterns of arm spasticity**

| Joint | Pattern | Relevant muscles |
|---|---|---|
| | **Type I** | |
| Shoulder | Internal rotation/adduction | *M. pectoralis major, M. teres major* |
| Elbow | Flexion | *M. brachialis, M. biceps brachii, M. brachioradialis* |
| Wrist | Flexion | *M. flex. carpi ulnaris, M. flex. carpi radialis* |
| | **Type II** | |
| Shoulder | Internal rotation/adduction | *M. pectoralis major, M. teres major* |
| Elbow | Flexion | *M. brachialis, M. biceps brachii, M. brachioradialis* |
| Wrist | Extension | *M. ext. digitorum, M. ext. carpi radialis, M. ext. carpi ulnaris* |
| | **Type III** | |
| Shoulder | Internal rotation/adduction | *M. pectoralis major, M. teres major* |
| Elbow | Flexion | *M. brachialis, M. biceps brachii, M. brachioradialis* |
| Wrist | Neutral position | *M. flex. carpi ulnaris, M. flex. carpi radialis, M. ext. digitorum, M. ext. carpi radialis, M. ext. carpi ulnaris* |
| | **Type IV** | |
| Shoulder | Internal rotation/adduction | *M. pectoralis major, M. teres major* |
| Elbow | Flexion | *M. brachialis, M. biceps brachii, M. brachioradialis* |
| Wrist | Flexion | *M. flex. carpi ulnaris, M. flex. carpi radialis* |
| | Pronation | *M. pronator teres* |
| | **Type V** | |
| Shoulder | Internal rotation/adduction | *M. pectoralis major, M. latissimus dorsi, M. teres major* |
| Elbow | Extension | *M. triceps brachii* |
| Wrist | Flexion | *M. flex. carpi ulnaris, M. flex. carpi radialis* |
| | **Spastic flexed hand** | |
| Fingers (metacarpophalangeal joints) | Flexion | *M. flex. digit. superficialis, M. flex. digit. profundus, Mm. interossei/ lumbricales* |
| | **Claw-shaped hand** | |
| Fingers (metacarpo-phalangeal joints) | Extension | *M. ext. digitorum, M. ext. indicis, M. ext. digiti minimi* |
| Fingers (phalangeal joints) | Flexion | *M. flex. digit. superficialis, M. flex. digit. Profundus* |
| | **Internal worm-like hand** | |
| Fingers (metacarpo-phalangeal joints) | Flexion | *M. flex. digit. superficialis, M. flex. digit. profundus, Mm. interossei/ lumbricales, M. abductor digiti minimi* |
| Fingers (phalangeal joints) | Extension | *M. ext. digitorum, M. ext. indicis, M. ext. digiti minimi* |

multifunction portable device using a Bo-ject needle disposable monopolar electrode with the output, 50×0.46 mm in size. The EMG device facilitated identification of the target muscle. During an injection, the needle electrode, which is an amplifier of the device, transmits a sound signal, which characterizes the muscle bioelectric activity, to an acoustic speaker, and the doctor hears and evaluates the degree of muscle activity at various sites. Therefore, EMG control enables identification of the most spastic areas in muscles involved in the pattern in order to perform injections exactly into the areas.

Evaluation of the treatment effect was performed after 1, 4, and 8 months. Patients in both groups received a standard set of physical rehabilitation procedures: physical therapy, postural management, and massage.

The pattern of upper limb spasticity was determined using the Arm Spasticity Pattern (ASP) scale [15]. Muscle tone was evaluated using the Ashworth scale, and the habitual activity level was evaluated using the Modified Barthel Index [17]. The Disability Assessment Scale (DAS) [18] was used to evaluate the effect of spasticity on important aspects of the patient's life: hygiene, dressing, limb position, as well as the presence of pain. In addition, a caregiver filled up the Clinical Global Impression (CGI) form [19].

Statistical processing of the study results was carried out using Microsoft Excel as well as Biostat (Publishing House Praktika, 2006) and SPSS 15.0 and Statistica 8.0 for Windows (Stat Soft Inc, USA) statistical software. The differences were considered statistically significant at $p<0.05$.

## Results

According to the ASP scale (**Table 1**), the most common spasticity patterns in the study were as follows: the type III pattern (upper limb with a flexed elbow and flexed wrist) occurred in 13 (44.8%) and 17 (53.1%) patients in the main and control groups, respectively; the type I pattern (an adducted and internally rotated shoulder) was in 9 (31.0%) and 9 (28.1%) patients of the

***Table 2*. General characteristics of study patients**

| Characteristic | Main group ($n$=29) | Control group ($n$=32) |
|---|---|---|
| Age, years | 42.8±12.4 | 40.7±11.9 |
| Gender | | |
| Males | 12 (41.4%) | 14 (43.8%) |
| Females | 17 (58.6%) | 18 (56.2%) |
| Etiology of spasticity | | |
| ACVA | 13 (44.8%) | 15 (46.9%) |
| Space occupying lesion | 7 (24.1%) | 9 (28.1%) |
| TBI | 9 (31.1%) | 8 (25.0%) |
| Number of months after spasticity onset | 12±5 | 11±7 |
| Total BTXA dose | 750—1,500 U | |
| Ashworth scale | 2.71±0.34 | 2.64±0.59 |
| Barthel scale | 45.26±7.81 | 47.03±6.23 |

***Table 3*. Therapy-associated changes on the Ashworth and Barthel scales**

| Scale | Group | Examination after treatment start, months | | | |
|---|---|---|---|---|---|
| | | after 1 m | after 4 m | after 5 m | after 8 m |
| Ashworth | Main | 0.94±0.37* | 1.93±1.06 | 0.52±0.24* | 1.46±0.87 |
| | Control | 1.19±0.54 | 2.04±1.13 | 0.93±0.48 | 1.87±0.91 |
| Barthel | Main | 58.14±8.71* | 51.73±6.12 | 62.54±8.3* | 54.21±7.64* |
| | Control | 51.63±7.32 | 49.46±7.14 | 56.17±6.27 | 50.18±6.27 |
| DAS | Main | 0.94±0.07* | 1.75±0.32 | 0.82±0.04* | 1.34±0.24* |
| | Control | 1.02±0.12 | 1.61±0.27 | 0.97±0.09 | 1.57±0.29 |

*Footnote.* * $p$<0.05 — significant differences between the main and control groups.

***Table 4*. Dynamics of changes in the passive limb function on the CGI scale**

| Upper limb function | Group | Examination time | | | | |
|---|---|---|---|---|---|---|
| | | Before treatment | 1 m | 4 m | 5 m | 8 m |
| Hand washing | Main | 9 (31.0%) | 12 (41.4%) | 10 (34.5%) | 12 (41.4%) | 10 (34.5%) |
| | Control | 12 (37.5%) | 13 (40.6%) | 12 (37.5%) | 14 (43.8%) | 12 (37.5%) |
| Nail cutting | Main | 7 (24.1%) | 10 (34.5%) | 8(27.6%) | 11 (37.9%) | 9 (31.0%) |
| | Control | 8 (25.0%) | 10 (31.3%) | 8(25.0%) | 10 (31.3%) | 8 (25.0%) |
| Putting the arm through a sleeve | Main | 11 (37.9%) | 21 (72.4%)* | 13 (44.8%) | 23(79.3%)# | 15 (51.7%) |
| | Control | 13 (40.6%) | 20 (62.5%) | 14 (43.8%) | 21 (65.6%) | 14 (43.8%) |
| Placing a splint | Main | 12 (41.4%) | 23 (79.3%)* | 13 (44.8%) | 25(86.2%)# | 14 (48.3%) |
| | Control | 15 (46.9%) | 25 (78.1%)* | 15 (46.9%) | 26(81.3%)# | 15 (46.9%) |

*Footnote.* * — significant differences between the main and control groups before and 1 month after the treatment start, # — significant differences between the main and control groups 1 month after 2 BTXA injections.

main and control groups, respectively; the type VI pattern (a spastic flexed hand) was in 7 (24.2%) and 6 (18.8%) patients in the main and control groups, respectively. For this reason, BTXA injections were performed into appropriate muscles in various combinations (**Table 1**).

Four weeks after the first BTXA injection, a statistically significant decrease in muscle tone and an improvement in the passive upper limb function were observed in both groups ($p$<0.05), but patients of the main group had more pronounced changes compared to those in the control group ($p$<0.05). However, no differences between the groups were observed after 4 months because of expiration of the drug clinical effect.

In association with rehabilitation therapy, a reduction in muscle tone in main group patients administered BXTA under EMG control was statistically significantly higher than that in patients without EMG control 4 weeks after the second BTXA course. Eight months after the study start, patients of the main group had statistically significant differences on the Barthel and DAS scales, indicating a higher efficiency of BTXA injections under EMG control (**Table 3**).

*Table 5*. **Planned and injected BTXA doses in patients of the main group**

| Patient | Spasticity pattern | Planned BTXA dose, U | Injected BTXA dose, U |
|---|---|---|---|
| 2 | I | 750 | 700 |
| 3 | II | 1,000 | 750 |
| 6 | I | 1,000 | 800 |
| 8 | III | 750 | 700 |
| 14 | III | 750 | 700 |
| 17 | I | 1,500 | 1,200 |
| 23 | III | 1,000 | 850 |
| 26 | II | 1,500 | 1,250 |

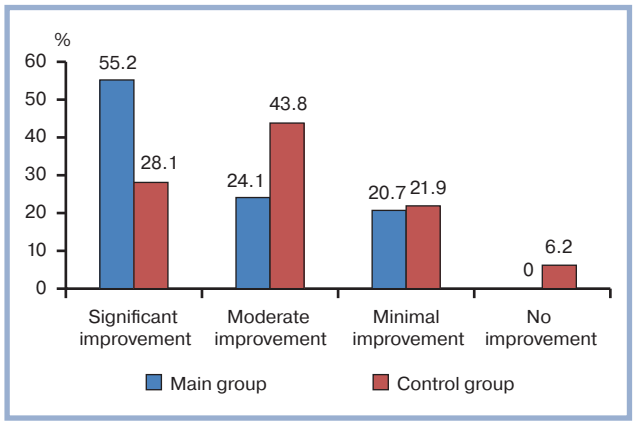
A caregivers' survey revealed that patients in both groups experienced a significant improvement in placing a splint as early as one month after the first and then second BTXA injections ($p<0.05$). Patients of the main group also had a statistically significant improvement ($p<0.05$) in putting the arm through a sleeve, while the positive changes observed in the control group were not significant. An improvement in hygienic measures (hand washing, nail cutting) was not statistically significant (**Table 4**).

**Table 4** presents the data provided by caregivers at the study end (after eight months). An improvement in the passive limb function was found to be 1.96 and 1.82 times more frequent in patients of the main and control groups, respectively. However, the differences were not statistically significant, which may be due to the small sample size (Figure).

Given the results of other authors [15], we reduced a planned BTXA dose in 8 (27.6%) patients of the main group (with EMG control) by 50—300 U (**Table 5**), which did not worsen the treatment results.

## Conclusion

This study demonstrated a good efficacy of BTXA injections under EMG control, which led to a reduction in increased muscle tone and an improvement in the passive function of the upper limb (compared to injections performed relying on the anatomical landmarks only). Furthermore, the use of EMG control reduced the botulinum toxin dose due to a more accurate analysis of injected muscle activity.




**Treatment efficacy according to the Clinical Global Impression scale**

A number of previous studies demonstrated the important role of the exact needle localization in the target muscle, drug injection in the immediate proximity to the myoneural junction, and diffusion of the botulinum toxin within the appropriate area of the target muscle [20, 21]. The lack of the botulinum toxin injection effect in spasticity treatment may also result from an inaccurate injection into the target muscle and drug diffusion to adjacent muscles.

For example, a study [22] demonstrated the efficacy of botulinum toxin injections for decreasing muscle tone in the biceps muscle of the upper limb. A better effect of directed botulinum toxin injections was observed: a greater decrease in muscle tone, reduced co-contraction phenomenon, and increased range of active elbow extension in the case of directed drug administration into the endplate region under EMG control and in combination with large drug dilution compared to undirected injections with low drug concentrations.

In the present study, we used a standard dilution volume of 2.5 mL per 1 vial; the number of injection sites was related to the muscle belly volume (1—4 sites, on average); drug doses were less than the mean doses recommended by the Consensus, which prevented side effects.

The European Consensus for the use of botulinum toxin therapy in spasticity suggests the necessity for further research to determine the most accurate techniques improving the efficacy of botulinum toxin injections because there are no comparative studies evaluating the accuracy of anatomical landmark-based botulinum toxin injections and the accuracy of botulinum toxin injections under ES and ultrasound control in adults with focal upper limb spasticity [12]. However, many specialists who use BTXA believe that injections do not require EMG control, except cases with complicated palpatory identification of the muscles. They also believe that the use of portable devices for EMG control

unreasonably increases discomfort for the patient, injection duration, and procedure cost [23, 24].

The present study clearly demonstrated that the use of EMG control during an injection in patients with upper limb spasticity led to a significantly better effect regarding a muscle tone reduction and an improvement in the passive upper limb function by more than 15%. Furthermore, EMG control did not cause significant discomfort and, in general, reduced the procedure cost through decreasing a drug dose.

## Findings

The optimal variant of botulinum toxin injections is their combination with electromyographic control, which may increase the efficacy of treatment of patients with upper limb spasticity. However, further research using a larger sample size is needed to determine, in particular, the minimum effective botulinum toxin doses because this is extremely important due to the prevalence of this problem.

**Authors declare no conflict of interest.**

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## Commentary

The topicality of the study is doubtless because the work is devoted to optimization of the management of patients with upper limb spasticity developed after common diseases, such as acute cerebrovascular disease, traumatic brain injury, and brain tumor. All professionals engaged with this issue are familiar with the complexity of rehabilitation of these patients.

One of the most modern and effective methods of treatment of upper limb spasticity is the use of the botulinum toxin. Its advantages include the effect locality, injections in any accessible area, effect duration, and lack of systemic adverse events. Botulinum toxin injections in spasticity patients lead to elimination of muscle hypertonus, which greatly facilitates the rehabilitation measures aimed at recovery of a motor deficit and significantly improves self-care or complex care for patients with this pathology. In this case, administration of the drug under electromyographic control showed a high efficacy associated with the fact that the drug is administered in the immediate proximity to the most tight muscle area. These important issues are addressed in the present work, which makes the problem topical and socially significant and defines the study aim to assess the efficacy of botulinum toxin therapy under EMG control in upper limb spasticity.

The reliability of the findings is confirmed by a sufficient amount of the studied material, application of goal-relevant techniques, and use of modern methods of statistical analysis. The results obtained by the authors using modern methods of research indicate achieving the study objectives. The data on a reduction in the planned drug dose due to electromyographic control are of particular interest.

The findings may be very useful to practitioners: neurologists, neurosurgeons, specialists in neurorehabilitation because electromyographic control will provide significant optimization of treatment of spastic patients.

I would like to wish the authors to follow the chosen direction and continue research, but also pay attention to another method used for accurate BTXA injections, namely ultrasonic control.

In general, the article is topical and is of scientific and practical novelty.

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