MEDICAL UNIVERSITY OF PLEVEN

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EMG changes in the Wernicke – Mann gait in post-stroke hemiparesis after injection of botulinum neurotoxin in the rectus femoris muscle

ABSTRACT

OF A DISSERTATION WORK FOR THE AWARD OF PhD DEGREE

Scientific supervisor prof. Vihur M. Kovachev, Ph.D.

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The dissertation work is written in 130 pages, of which literature review – 54, aim, tasks, materials and methods– 18, own studies – 17, conclusions, contributions, list of publications, related to dissertation workс– 7, bibliography – 14. Bibliography includes 210 literary sources, of which 33 are in Cyrillic and 177 are in Latin.

The dissertation work contains 11 tables and 32 figures.

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CONTENTS

ABBREVIATIONS

AB antibodies

AC acetylcholine

BoNTA botulinum neurotoxin A

BT botulinum toxin

BF biceps femoris muscle

SpC spinal cord

Sp – spine

AJ ankle joint

ADLs activities of daily life

EMG electromyography

KJ knee joint

MP medicinal products

MU motor units

ICF international classification of functioning, disability and health

CVD cerebrovascular disease

MT muscle tone

SwP swing phase (of the gait cycle); **PreSwP** – pre-swing phase

NT neurotoxin

SM striated muscles

NSAIDs non-steroidal anti-inflammatory drugs

RM range of motion

LMS locomotor system

StP stance phase (of the gait cycle)

PVM paravertebral muscles

WeMG Wernicke – Mann gait

DMA duration of muscle activity

PR proprioreceptors

RF rectus femoris muscle

CKR clasp-knife response

CVS cardiovascular system

HJ hip joint

US ultrasound

CNS central nervous system

GC gait cycle

HMS a group of muscles, flexors of the knee joint

MAT muscle activation time

RF m.rectus femoris

TKEO Teaker – Kaiser energy operator

1. Introduction

Cerebrovascular diseases are a worldwide medical and social problem due to the high morbidity and mortality they lead to, as well as disturbance in the daily life activities of the patients due to the pathological gait and disability they cause. According to the World Health Organization, 15 million people suffer from stroke every year worldwide, of which 5 million die and 5 million remain permanently disabled. WHO reports that in 2018 Bulgaria ranks first in deaths from cerebrovascular diseases in Europe according to the standardized coefficient, which was 6.2 times higher than the one in France. In 2020, the standardized indicator for the rate of fatal outcomes was 317.4 per 100,000 population, while in 2021 there was an increase to 339.5 per 100,000 population. According to Eurostat, in 2016 cerebrovascular diseases (CVD) are among the most common causes of death, along with the ischemic heart disease and malignant neoplasms of the respiratory system. According to the Stroke Awareness Foundation in the United States, stroke is the number one cause of long-term disability in adults. In the United States, 795,000 people suffer from stroke each year, more than 129,000 of whom with a fatal outcome. Statistics show that CVD is the 5th leading cause of death in America. (https://www.strokeinfo.org/3d-flip-book/2023-prospectus/). In 2022, more than 45,000 people died from stroke in Bulgaria. Cases of acute ischemic stroke (AIS) are prevalent – 85.6% (43,578 cases), with 51.2% of the cases being women [Andonova S et al., 2010; Tityanova E et al., 2010; Titianova E et al., 2009]. According to the country’s health profile in the EU for 2021, the diagnosis of stroke in Bulgaria represents a large part both of the avoidable mortality with good prevention, and the avoidable mortality with good treatment. Premature deaths from stroke are 23% of all deaths due to otherwise treatable causes – State of Health in the EU.

Stroke affects people of various ages, with the consequences being severe disability - motor disorders, difficulty in self-care, professional and social maladjustment, and often depressive states. About 80% of stroke patients overcome the dependence on foreign aid, about 26% of the patients have dementia and impaired communication, and about 20% remain confined to bed

(Tityanova, E., 2015). Causes of CVD are considered risk factors such as overweight, diabetes mellitus, unhealthy diet, alcohol abuse and smoking, stress, hypodynamia, leading to atherosclerosis of the brain vessels, arterial hypertension, chronic ischemic heart disease, etc. (Yancheva, S. et al., 1998). These epidemiological data indicate the social significance of the problem and the need to introduce a complex neurorehabilitation algorithm in patients with CVD and sensory motor deficits due to strokes.

Stroke patients, in addition to neurological and social status disturbances, often face difficulties moving, self-caring and walking, which hinders their daily life activities. One pathognomonic pathology in gait in these patients is the appearance of the Wernicke-Mann gait (WeMG), in which the spastic limb knee, while in the swing phase (SwP), is inflected less than in the normal human gait. (Figure 1)(Sutherland,D.H., and J.R.Davids. Common gait abnormalities of the knee in cerebral palsy. Clin. Orthop. Relat. 288:139-147, 1993). In normal movement with proper gait, the hip joint (HJ) and the knee joint (KJ) are rapidly inflected during the pre-swing phase (PreSwP) and the first sub-phase (initial swing) of the SwP, with subsequent stretching forward of the swing leg and there is sufficient space between the two lower limbs. In contrast, the pathological gait in Wernicke-Mann hemiparesis leads to insufficient and disturbed space between both legs, pathological foot slip forward, acceleration, decreasing the frequency and length of the steps, thus limiting the functional, correct performance of the movement. Several potential causes of the pathological WeMG in stroke patients are described in literature. One of the main causes mentioned in literature is the overactivity of one of the most important muscles of the lower limb, occupying central part in the gait cycle, namely the quadriceps femoris muscle, especially one of its heads - the rectus femoris muscle (RF), during the SwP (Anderson, F.C., S.R. Goldberg, M.G.Pandy, and S.L.Delp. Contributions of muscle forces and toe-off kinematics to peak knee flexion during the swing phase of normal gait: an induced position analysis. J. Biomech.37:731-737, 2004) Another possible cause of the described ones is the reduced push-off of the foot, during the double limb support phase, due to weakness in m. gastrocnemius (Kakebeeke TH, Lechner H, Baumberger M, Denoth J, Michel D, Knecht H. The importance of posture on the isokinetic assessment of spasticity. Spinal cord. 2002; 40:236-243), as well as the reduced flexion range in the HJ during the PreSwP. (Rabita G, Dupont L, Thevenon A, Lensel-Corbeil G, Pérot C, Vanvelcenaher J. Quantitative assessment of the velocity-dependent increase in resistance to passive stretch in spastic plantar flexors. Clin Biomech (Bristol, Avon). 2005;20:745-753)

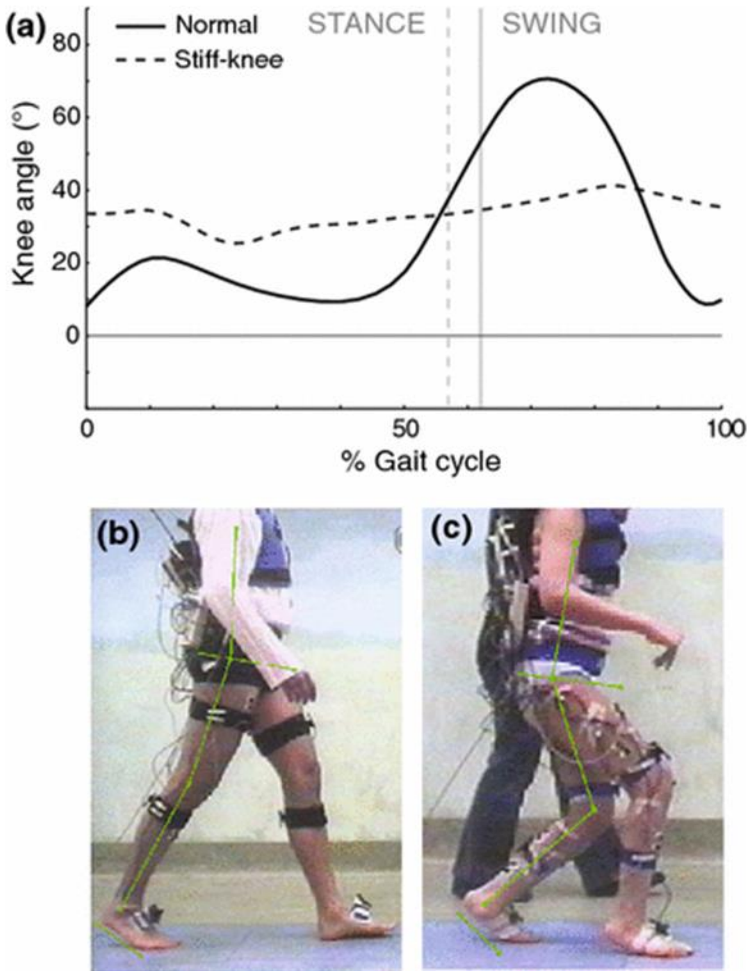

Figure №1. (A) Example of a Wernicke-Mann gait, a locked knee in flexion and extension (dotted line), compared to a normal angle of the KJ during physiological gait (continuous line). The Wernicke-Mann gait is presented by a limited active range of motion (RM) and a severely reduced knee flexion in SwP (Sutherland and Davids,179). (b, c) The angle of flexion of the knee joint, which is different in both gaits, is presented, which limits the progression of the foot in the SwP. The figures are from separate experimental studies. (Simpson, D.M., Gracies, J.M., S.A.,Barbano,R.,Brashear,A., the BoNTA/TZD Study Team. Botulinum neurotoxin versus tizanidine in upper limb spasticity: a placebo-controlled study.J.Neurol.Neurosurg.Psychiatry,2009,80,380-385)

Many foreign studies aimed at investigating the causes of the Wernicke-Mann pathologic gait, used techniques by simulating the gait in dynamics, as well as techniques for induced acceleration in order to study the role of spastic damaged muscles during the pre-SwP for flexion of the swinging leg. These studies were conducted and analyzed by introducing an innovative whole-body simulation

(Giglia E. To Google or not to Google, this is the question. European Journal of Physical and Rehabilitation Medicine, 2008, 44, 2, 221227) or only of the lower limb in the swing phase, at the same time, defining the hip motion. All of these studies have provided important insights and discoveries about the individual role of the muscle function for the spastic WeMG. However, the complexity of the types may also hinder a more conceptual discovery of the causes of impaired physiological gait.

Multiple studies have been conducted around the world that have proven the effectiveness of applying botox to spastic muscles in patients with motor neuron damage. Many of the authors of these studies believe that to overcome or reduce the muscle spasm of the paretic lower limb, which impairs the gait in stroke patients, it is necessary to apply an effective agent locally to the muscle, since the myorelaxants used so far are not effective enough to reduce muscle spasm and are not specifically targeted at the muscle responsible for the walking difficulty, but act generally to relax all muscles. Also, the myorelaxants used so far often lead to side and adverse effects, such as general weakness and fatigue. Injecting BoNTA into the spastic muscle would be a good choice for dealing with spasticity, as it acts locally on the cause of gait disturbance and would be effective in reducing spasm in this muscle and improvement of autonomous gait. (Milanov, I. Treatment and neuromodulation with botulinum toxin. Medicine and Physical Culture, Sofia, 2017, p. 22-101). This method of treatment has not yet been studied and investigated in Bulgaria. Therefore, our study has been prepared to monitor whether the spasm of the RF muscle responsible for the flexion in the knee joint is reduced after application of BoNTA in patients with stroke hemiparesis.

Gait disturbance can be a symptom of many different neurological and orthopedic diseases. One of the most common gait disorders occurs in hemorrhagic or ischemic cerebrum stroke, the main consequence of which is hemiparesis. Wernicke-Mann gait occurs when the pyramidal tract is affected and the development of a central, spastic paresis of the muscles of hemiparetic type. The gait is characterized by swinging out and rotation forward of the paretic lower limb, which is tight and stretched in the hip, knee and ankle joint. The foot is dragged on the ground, describing a circular motion, while the arm on the same side is folded and bent to the body. This type of spastic gait can be observed in a cerebrovascular disease, multiple sclerosis, cerebral palsy, etc. (Milanov, I. Treatment and neuromodulation with botulinum toxin. Medicine and physical culture, Sofia, 2017, p. 22-101)

To reduce the muscle spasm during this gait type of motion, due to the damage to the central motor neuron, there is still no fully effective and lasting way, except for oral administration of myorelaxants, mainly Baclofen. So, an innovative, easy-to-implement and effective treatment is needed to reduce muscle spasm without causing fatigue or other side effects to all organs and systems. Botulinum toxin can be a good means to achieve this goal in stroke patients with severe hemiplegia. Injections of BoNTA would be a good option for managing muscle spasticity that causes the pathological gait. We believe that the medicine and the clinicians in Bulgaria need a new treatment method to improve flexion and range of motion in the knee joint, the velocity and strength of movement in such patients. Patients with hemiparesis need gait improvement and reduction in the spasm of rectus femoris for maximum recovery of ADLs. We believe that a complex algorithm is needed to treat stroke patients, including physiotherapy and rehabilitation, in parallel with an effective means to reduce muscle spasm in order to improve quality of life, restore impaired motor function, self-care and walking (Koleva, I., 2008).

2. Purpose and tasks

Purpose:

The purpose of this study was to follow up and evaluate the use of complex rehabilitation, including treatment with BoNTA as a treatment agent to reduce the muscle spasm of rectus femoris in stroke patients with hemiparesis and Wernicke-Mann gait, on quality of life and self-reliance in everyday activities.

Tasks:

1. To monitor and assess how well the rectus femoris muscle is affected by the manipulation with botulinum toxin.
2. To monitor how well the side effects of hemiparesis and ADLs are affected in stroke patients.
3. To assess the effect of the injection to rectus femoris muscle activity in the StP and SwP of the gait cycle by dynamic 3D simulation of the gait of patients after a suffered stroke.
4. To examine the relative contribution of the injection to rectus femoris muscle activity in the the StP and SwP on the knee joint flexion.
5. To assess the functional capacity of patients before and after the injection.
6. To assess the patients' ability for social and professional readaptation.

3. Materials and methods

3.1. Materials

Twenty-two patients after stroke with chronic hemiparesis (at least 6 months after the stroke) and Wernicke-Mann gait were included in the study. The main inclusion criteria were: age over 18 years, hemiplegia, reduced range of flexion of the KJ during the swing phase of the gait cycle, ability to walk 8 meters without aids. Patients with RF spasticity between 1+ and 3 of the modified Ashworth scale and who are able to actively, not passively, increase the walking speed.

3.1.1. Characteristics of the participants

The characteristics of the included examined patients are provided in Table №1.

Patient No	sex	age	Stroke period (years)	height (cm)	weight (kg)	Side of hemiplegia	Type of stroke	Spasticity before RF BoNTA	Spasticity after RF BoNTA
1	M	46	2	187	74	L	Hemo	2	1+
2	M	75	9	158	55	R	Isch	2	1
3	M	61	10	166	73	L	Isch	2	1
4	M	47	7	160	74	L	Isch	3	2
5	M	62	7	159	52	L	Isch	1+	1+
6	M	43	16	180	64	L	Hemo	3	2
7	M	46	2	169	82	R	Isch	1+	1
8	M	72	10	171	73	R	Hemo	1+	0
9	M	45	10	151	66	L	Isch	3	2
10	M	45	9	181	93	R	Isch	2	1+
11	M	48	11	178	74	R	Hemo	1+	0

12	M	47	10	172	100	R	Hemo	1+	1
13	M	44	5	181	87	L	Isch	3	2
14	M	59	11	173	99	L	Hemo	1+	1
15	F	46	15	175	82	R	Hemo	1+	0
16	F	43	13	157	58	R	Hemo	2	1
17	M	66	6	168	50	R	Isch	2	1+
18	M	73	11	170	120	L	Isch	3	2
19	F	68	9	157	64	R	Hemo	3	1
20	F	48	15	191	70	L	Isch	1+	0
21	M	58	16	157	60	R	Hemo	1+	1
22	F	60	44	165	60	R	Isch	1	1

Table №1. Characteristics of the participantsл. M-male, F-female, L-left hemiparesis, R-right hemiparesis, Hemo-hemorrhagic, Isch-ischemic

They underwent a clinical examination and gait monitoring; they had a reduced or missing range of flexion of the KJ and ability to walk without a walking aid on a treadmill. The patients had had stroke for 6 months, i.e. they were considered chronically ill. In the acute phase, all patients had been treated in a neurological ward and then underwent a program of physiotherapy, rehabilitation and kinesitherapy. The patients continued to conduct regular physical therapy and rehabilitation (20 minutes per procedure, at least 5 procedures per day, 7 days per week). The underlying drug therapy of the patients remained unchanged during the study.

3.2. Methods of research and treatment

3.2.1. Analysis of the gait and movement

Two analyzes were carried out: before the manipulation (Pre-BoNTA at normal and maximum gait velocity) and 4 weeks after the injection (Post-BoNTA at normal and maximum gait velocity). The second period was analyzed after 1 month, because this is the period for the botulinum neurotoxin to reach its clinical effect.

The gait was analyzed by three-dimensional analysis, which included kinematic, electromyographic and energy measurements. The movement was recorded and performed using a system for analyzing and recording movement with 4 optoelectric cameras in a laboratory. The equipment we used in the laboratory consisted of: Motion capture system - 3D angles of joints, joints, velocity and acceleration, 4 chambers; Telemetric EMG unit - models of dynamic activity of the muscle, electrodes. (Solnik et al., 2010).

All data were recorded simultaneously on a force measuring track (Figure№2).

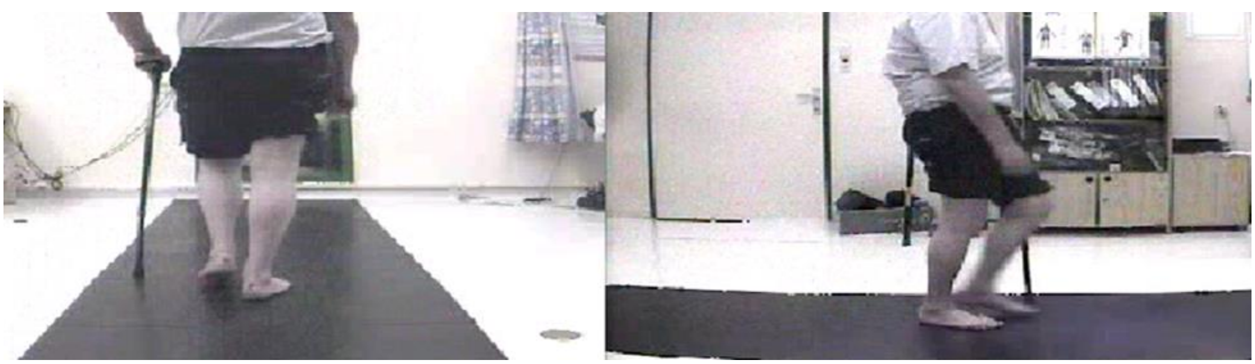

Figure №2. Force measuring track for capturing the gait cycle in the specialized walk-investigating laboratory

The participants walked barefoot. For each patient, at least 10 consecutive walking cycles were recorded and averaged in order to analyze separately and in total each variable. 30 reflective markers were placed on the relevant anatomical points of the muscles involved in the gait, according to Helen Hayes markers. The trajectory of these markers was recorded using 4 infrared cameras and a low-pass filter. A record of the following gait characteristics was made (Figure №3.)

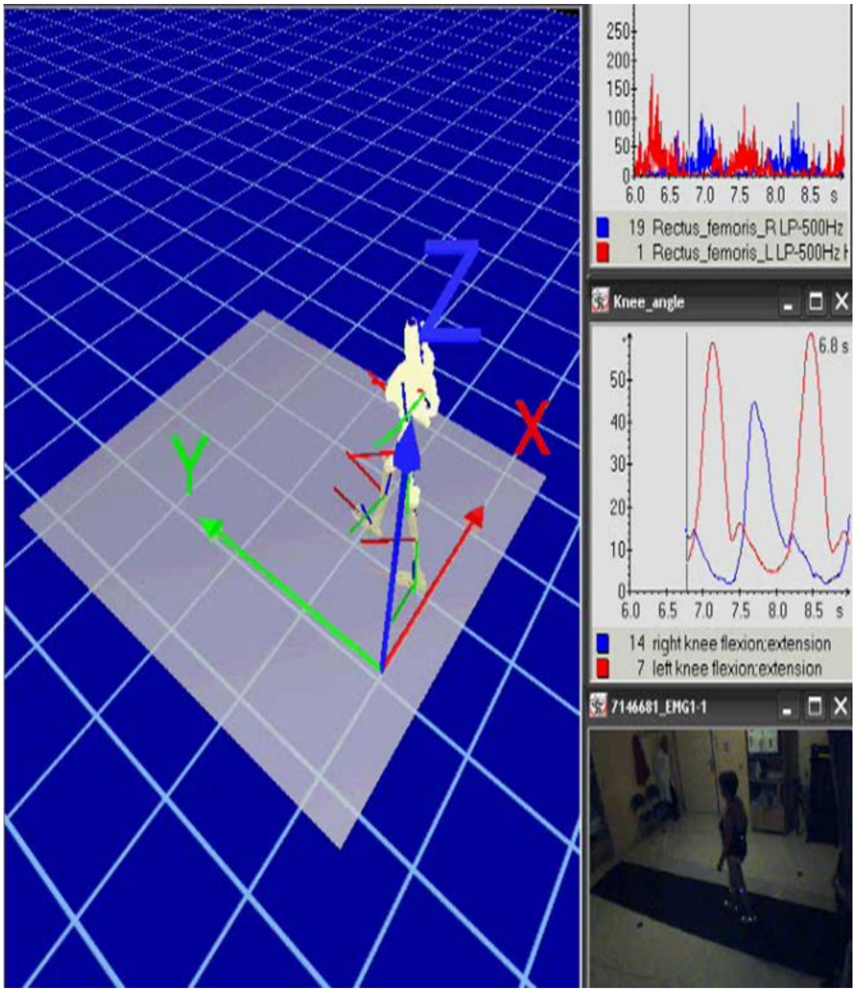

Figure №3. Recording of the gait characteristics Step length and velocity, 3D range of motion of the joints, Muscle activity

The calculation of the spatial-temporal characteristics and kinematics of the joint was carried out using the Orthotrack 6.5 software.

3.2.2. Clinical examination

The clinical examination was conducted at the beginning of the study, in dynamics and one month after the injection. It consisted of a detailed somatic and neurological status, specialized scales were used to assess the focal neurological symptoms and a scale to determine the degree of neurologic disability – Rankin scale.

Neurologic disorders (upper and lower limb motor function, muscle tone, sensitivity, range of motion, tendon periosteal reflexes) were evaluated using the stroke assessment tool (NIHSS scale) validated by the Rankin scale.

The spasm of the quadriceps femoris and RF muscles was evaluated using the modified Ashworth scale (MAS) (Bohanon and Smith, 1987).

3.2.3. Assessment of EMG parameters

An EMG recording of the parameters of the rectus femoris muscles of the paretic lower limb (on the side of the hemiparesis) of the patient was performed during walking. This muscle was examined because of its participation in the KJ motion during pre-SwP and SwP (Fox and Delp, 2010) and because previous studies have shown that the EMG activity of this muscle changes from BoNTA (Stoquart et al., 2008). Three bipolar surface electrodes with built-in transmitters (MA311, Motion Lab, Jerusalem, Israel) were placed directly on the skin, according to SENIAM instructions (Hermens et al., 2000). The EMG sensors consisted of stainless-steel electrodes with double-differential transmitters. The two active electrodes measured 12 mm in diameter, and the distance between the electrodes was 17 mm. All EMG signals were selected at 1000 Hz.

3.2.4. Duration of muscle work

The Teager-Kaiser (TKEO) method was used to calculate the energy and duration of muscle work during the gait cycle (Solnik et al., 2010). This method allows measuring muscle work at the beginning and end of the movement, which is obtained from the calculation of the amplitude and frequency of the EMG signal. All EMG signals were filtered with a second low-pass Butterfly filter with a correction and a limit frequency of 10 Hz in order to be processed (Lauer and Prosser, 2009).

3.2.5. Frequency

The frequency and duration of the EMG signals (Lauer et al., 2005) were analyzed using continuous wavelet transform (CWT). We analyzed the signal from the time series of rectus femoris muscle before and after the manipulation, using Morlet wave as the main function (Torrence and Compo,1998) and linear scale (Lauer et al., 2005). The analysis from the CWT is visualized on a so-called scalogram using three-dimensional analysis. Thus, from the scalogram we determined the instantaneous mean frequency (IMNF) for each phase of the GC. The instantaneous mean frequency was calculated based on the individual instantaneous frequency curve for each patient (Lauer et al., 2005) and for rectus femoris throughout the gait cycle.

3.2.6. Manipulation – introduction of BoNTA

Botulinum neurotoxin consists of proteins derived from the gram-positive anaerobic bacterium Clostridium botulinum, which is used as a medicinal product.

In this study, we make use of the fact that when injected into a particular muscle, it will act on the neuromuscular synapses and block the release of acetylcholine.

The Botulinum neurotoxin was injected into a part of the quadriceps muscle of the thigh - RF on the hemiparetic lower limb of all enrolled patients (Figure №4).

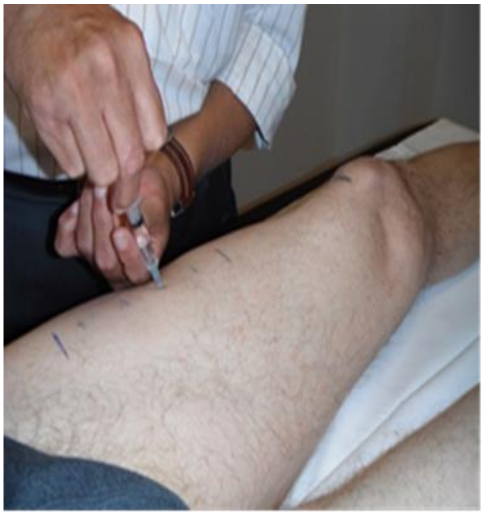

Figure №4. Injection of botulinum neurotoxin in rectus femoris muscle

Between 150 and 200 units of Botulinum toxin type A, diluted to 50 U/ml, were injected into three anatomical points under EMG control to check the correct position of the needle: 1. in the junction of the middle and distal third of RF; 2.in the middle of RF (midpoint); 3. and in the junction between the proximal and middle third of RF (Milanov, I. Treatment and neuromodulation with botulinum toxin. Medicine and physical culture, Sofia, 2017, p. 22-101).

All medical interventions were performed by the same doctor. The dose and technique of the medical intervention were chosen so as not to differ from other foreign studies (O’Brien, 2002), which have studied the effect of the injection of BoNTA on the knee flexion in patients with hemiplegia after stroke with pathognomonic Wernicke – Mann gait. The dose determination was strictly individual according to the severity of each patient's rectus spasm, again according to O’Brien's instructions. All patients had pathology in the EMG activity of RF during the SwP of the gait, before the injection.

3.2.7. Protocols

The protocols contained an initial clinical neurological examination and analysis of active movement prior to medical manipulation with the injection of botulinum neurotoxin. After evaluation of the examination, the manipulation was carried out and neurological examinations and gait assessments were conducted again after 1 month to follow up the effect of the injection. The most comfortable walking speed on the force measuring track treadmill before the BoNTA was determined individually for each patient. Thus, the two periods studied were performed at the same walking speed. The administered medication therapy and rehabilitation remained the same for each patient during the study.

4. Own studies

4.1. Outcomes on the number of steps

In all 22 hemiparetic patients enrolled in this study, there was a significant change. The procedure was well tolerated by all patients without any side effects. The outcomes related to the number of steps have significantly improved after the BoNTA from 15 to 17.

The injection of botulinum neurotoxin into rectus femoris contributed to positive effects on NIHSS, with outcomes increased from 48 (before the manipulation, 36-57) to 50, and on muscle spasticity, with outcomes in the Duncan-Eli test reduced by 1 unit. The outcomes of the Ashworth scale decreased from 3 (before, 1-3) to 1 (after BoNTA, 0-3). The step velocity has also increased. The average walking speed increased by 50±10 m/s. The frequency of the steps mildly increased after the intervention by 78 ± 9 steps/min compared to the values measured in normal gait before the manipulation 65 ± 6 steps/min. The time for activation of the spastic muscles decreased significantly, and the time for activation of rectus femoris muscle decreased from 75 to 73. (Table №2).

Variable	**Before BoNTA injection**	**After BoNTA injection**
NIHSS outcome	48 (36-57)	50(38-68)
The Ashworth scale score	3 (1-3)	1 (0-3)
Number of steps (steps/min)	78±9	80± 12
KJ angle	26± 13	31 ± 14
M (M/kg)	46±13	45±11
Biceps femoris OBA (%)	60±14	47± 18
Rectus femoris OBA (%)	73± 24	70+_22
Energy expenditure during walking ($J\text{-}kg^{-1}\text{-}m^{-1}$)	2.2±1.1	1.9±1.1

Table №2. Outcomes obtained

4.1.2. Outcomes on the range of motion of the KJ

The outcomes are presented in Figure 5B. The range of flexion of the KJ after BoNTA injection increased to 3+/5 in the manual muscle testing (MMT) from 1/5 before injection during the SwP of the gait cycle. At the end of the stance phase, flexion range of 77° was achieved, corresponding to one-third of the values measured in normal gait. The flexion velocity of the KJ decreased at the beginning of the swing phase and reached negative values close to those of the extension. Then the flexion range increased again, so the knee velocity expressed a double concave (Figure № 5(A). After the BoNTA injection, the flexion range of the knee improved, and this double concave disappeared. The flexion range and velocity of the knee during the stance phase increased from 85 ° ± 63 ° before to 110 ° ± 75 ° after BoNTA. The angle of the KJ measured with a goniometer increased by 5° after the injection (Figure №5B)

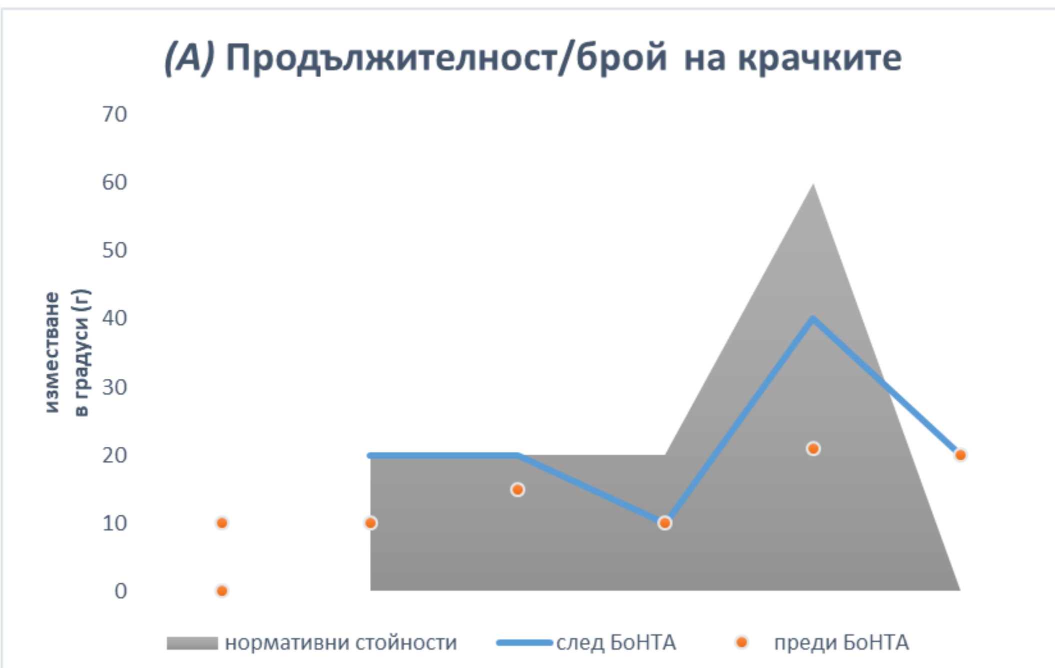

Figure №5A. Outcomes on the number of steps

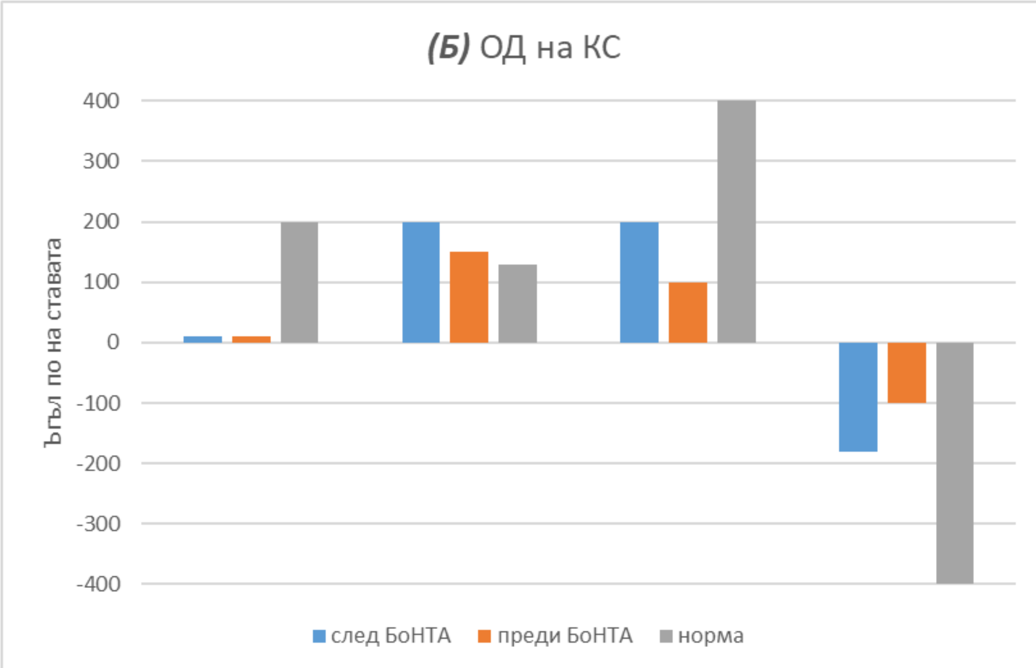

Figure №5B. Outcomes on the range of motion of the KJ

4.1.3. Outcomes on the knee strength

The strength of the knee joint in stroke patients before and after the injection was measured comparatively. The strength of the knee joint is presented in Figure 5(C). In patients before injection, the strength of the knee indicated low values measured in the manual muscle testing, which is associated with the contraction of RF of the quadriceps femoral muscle to slow knee flexion at the end of the stance phase. The strength of the knee joint before BoNTA was greatly reduced in patients measured by MMT 1/5. After the injection of BoNTA, the strength increased significantly 3+/5.

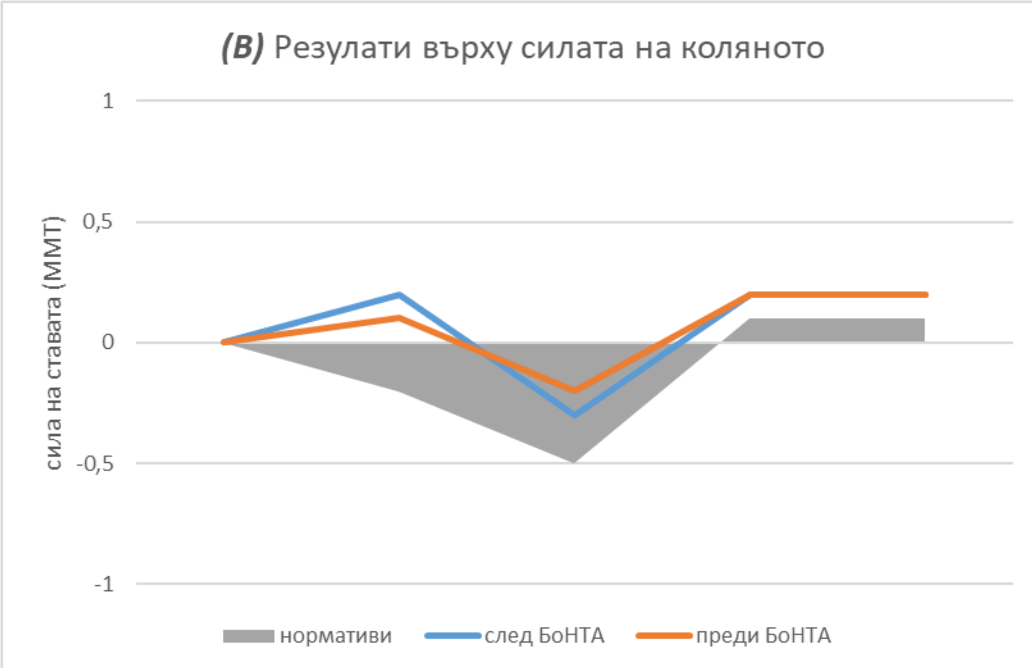

Figure №5C. Outcomes on the strength

4.1.4. Outcomes on the time of action of RF

The time of action of the medial and lateral head of m. quadriceps femoris and RF was monitored. It was noticed that the activation time of the examined heads of the quadriceps femur before BoNTA had increased for the medial and lateral heads and was almost constant for rectus femoris. The time of action of RF after injection is reduced, and that of the medial and lateral heads is more noticeably reduced. After averaging the outcomes of all studies, it was found that the time of action of RF decreased significantly after the injection from 68% ± 17% to 58% ± 13% and respectively for the other two heads from 60% ± 14% to 47% ± 18%.

4.1.5. Outcomes on the energy expenditure through walking

We compared that the energy expenditure through walking of the patients in the study before the manipulation (2.2 ± 1.1J/kg) was greater than the energy expended by the patients through walking after the injection (2.1 ± 0.5J/kg). An insignificant reduction in the net energy expenditure was observed when patients walked after the injection (1,9 ± 1,1 J/kg). Patients were divided into groups according to the extent of active flexion of the knee measured by the MMT. In patients from the group without flexion (up to 2+/5 by MMT) in the knee before the injection, their knee flexion and energy expenditure were not fully affected. In the other patients where we measured mild knee flexion, but still incomplete, before the injection (from 3/5 by MMT to 4-/5 by MMT), improvement was observed after treatment and the energy expenditure in walking after manipulation was reduced 4.2± 1.2 to 3.1 ± 1.3 J-kg-1-m-1 (Table 2).

4.2. Variations in gait kinematics

4.2.1. Indicators of the hip joint

The analysis of the studied variations in the hip joint kinematics is presented in Table 7 and shows that the maximum hip joint flexion in the first phase of the gait cycle is mildly increased in spastic active gait before injection (P = 0,0008), as well as in the gait after the intervention P = 0,005. No relation is found between the improvement in hip flexion before and improvement in knee flexion after manipulation in the muscle (R = -0.03 P – 0.58).

4.2.2. Indicators of the knee joint

The outcomes of the kinematic indicators showed that the maximum flexion of the knee increases during the active hemiparetic gait (P = 0.00001) (+3.4 °), increases also after the intervention of m. rectus femoris (P = 0.0002) (+5.2 °) (Figure 6). No relation is found between the percentage ratio of improvement in the knee flexion in fast hemiparetic gait and improvement in the knee flexion in maximal velocity after the intervention (R = 0.36; P = 0.023).

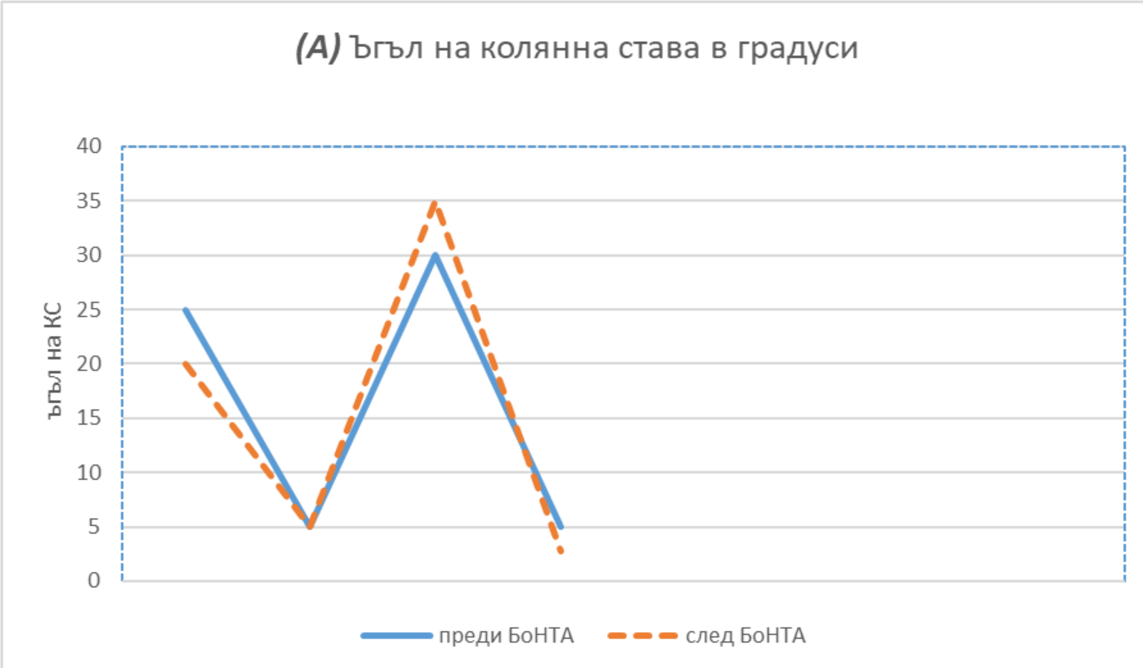

Figure №6. Increase in maximal flexion with 3,4* after the injection

4.2.3. Indicators of the ankle joint

The outcomes showed that the range of dorsal flexion in the ankle joint during the stance phase of the gait cycle did not change significantly either in the hemiparetic untreated gait (P = 0.21) before the manipulation or after the treatment of the spasm (P = 0.83). Also, no relation was found between the range of the peak dorsal flexion of the ankle in the stance phase in untreated spastic active gait (before RF BTX-a injection) and the percentage improvement of active knee flexion in active maximal gait (after reduction of the spasm).

We monitored the relation between the percentage of variation in the knee joint range of motion in plantar flexion during the active gait after the intervention and the percentage of variation of the knee joint maximal flexion after the intervention – no significant correlation was found (R = 031; P = 0.15)

4.3. Changes in gait during the toe-off phase

4.3.1. Hip joint

The goniometry results indicate that the measured angle of motion of the hip joint during the hip joint displacement in the toe-off phase of the gait cycle mildly increases when walking on the force measuring track before the manipulation, as well as after the injection in the spastic muscle, respectively 84 ± 32°/s and 96 ± 35.0°/s). Figure №7.

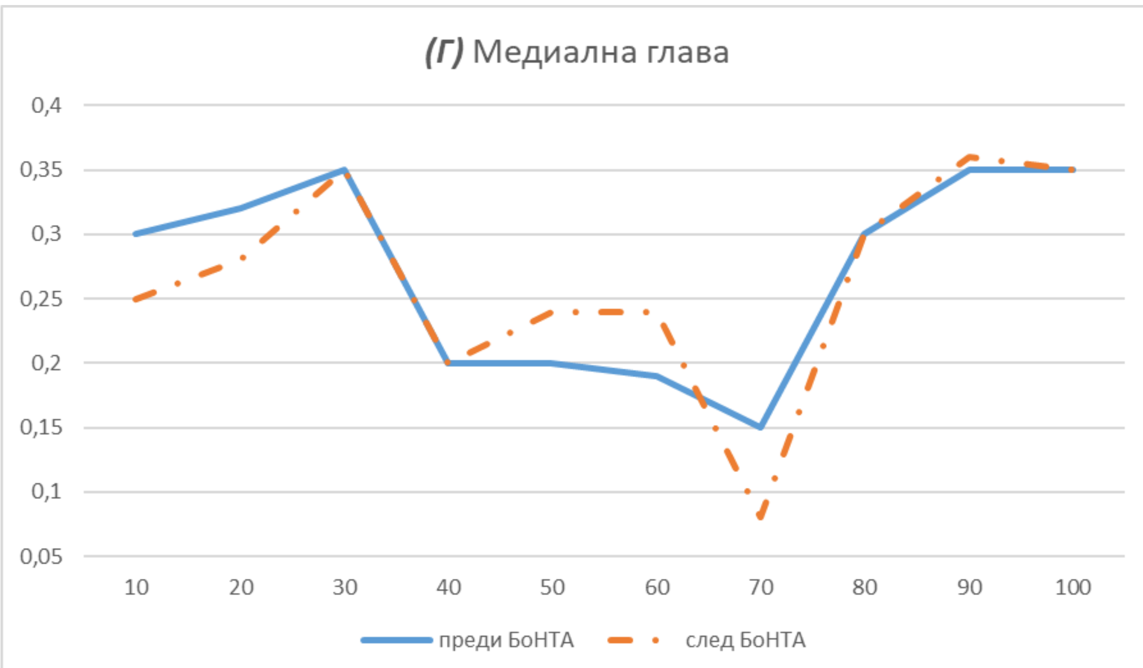

Figure №7. Variations in HJ kinematics.

4.3.2. Knee joint

The goniometry results indicate that the measured angle of motion and the displacement velocity in flexion in the knee joint during the toe-off phase of the gait cycle, mildly increases in active gait before the intervention, as well as after the intervention to reduce spasm, respectively <180±100°/s; 217±102°/s and 212±100°/s) (Table 3).

Improvement of knee flexion after botox injection in %	R	P
Improvement of gait velocity	0.21	0.9
Improvement of the HJ flexion	-0.03	0.78
Improvement of KJ flexion	0.36	0.024
Improvement of HJ flexion velocity	-0.03	0.58
Improvement of dorsi/plantoflexion	-0.28/-0.067	0.11/0.57
Improvement of the angle of the KJ range of motion	0.36	0.023

Table №3. Variations in flexion after the intervention compared to other parameters

4.3.3. Ankle joint

It was established that the maximum of the plantar flexion of the ankle joint in an active fast gait on the measuring track during the toe-off phase is not associated with the maximum flexion of the knee after the intervention with the toxin (R=0.24; P=0.21). Moreover, the angle of motion in maximum dorsal flexion in the toe-off phase increases significantly in fast active walking on the treadmill before the manipulation (P = 0.00007), as well as after the manipulation (P = 0.003, respectively 73 ± 63°/s; 105 ± 100°/s and 89 ± 49°/s).

5. Conclusions

1. in patients with hemiplegia and spastic gait caused by RF spasticity, evaluating the results during spontaneous gait may help the physician to select patients who benefit maximally from BoNTA injection to combat spasm.

2. Injection of BoNTA into the spastic rectus femoris muscle may be an effective therapy in patients with hemiparesis and Wernicke-Mann gait after stroke, especially in patients with known flexion contracture of the knee (> 10 °).

3. Percent improvement in knee joint flexion in the swing phase before injection may be a useful predictor of increased knee joint flexion after muscle injection in patients with chronic hemiparesis

4. A combined approach can be used to treat RF spasm in stroke patients presenting with Wernicke-Mann gait, including rehabilitation and physical therapy to improve the range of flexion of the knee joint during movement, as well as BoNTA injection in the spastic muscle. A combined rehabilitation program involving injection can accelerate the reduction of spasticity, leading to an improved gait pattern and increased daily independence and social engagement of the patient.

6. Contributions

6.1. Original contributions:

1. The effect of botulinum neurotoxin injection into spastic RF muscle on knee flexion in patients with hemiparesis after stroke was determined for the first time.
2. It is proven for the first time that if the patient can not actively (independently) increase the speed of movement the number of their steps, respectively the flexion of the knee, then this type of treatment can be applied to the other muscles responsible for the movement of the lower limb. In other words, patients with slow gait Wernicke-Mann and RF spasticity can be improved by injection into rectus femoris muscle. Conversely, in patients with the same disease but with a very slow Wernicke-Mann gait improving the swing phase of the gait cycle should be the focus of treatment
3. For the first time it is established that 3D motion analysis is not necessarily required. Simple equipment such as an electric goniometer or special insoles with a built-in measuring device is sufficient. Therefore, this type of analysis can be used by a large number of doctors in clinical practice with minimal costs.
4. It is established for the first time that patients with impaired spastic-paretic type of gait are able to increase knee flexion in the Swing phase during the fast gait, then they should improve the pathological gait after the injection of BoNTA in the RF. Patients who do not increase knee flexion should probably be treated with another method.
5. It is found for the first time that the knee angle increases and the knee flexion increases accordingly in the swing phase of the gait cycle after botulinum neurotoxin intervention of the spastic RF muscle.

5.2. Confirm contributions:

1. The connection between the muscle spasm of the RF and the pathological spastic-paretic Wernicke-Mann gait in hemiparesis is confirmed.
2. The reduction of muscle spasm in RF after botulinum neurotoxin injection is confirmed.
3. The increase in movement dynamics and social and psychological well-being of patients with hemiparesis after botulinum neurotoxin injection is confirmed.
4. It is confirmed that the improvement of hip flexion in the conditions of fast walking on the force measuring track is related to the increase in the range of motion of the knee in the swing phase after the botulinum intervention
5. It is confirmed that the injection of the spastic muscle, there is an improvement in the amount of plantar flexion of the ankle joint under conditions of fast walking.
6. It is confirmed that a combined approach can be used in patients with stroke and Wernicke-Mann gait due to RF spasticity including a rehabilitation program to improve knee flexion during gait and injection of botulinum neurotoxin into the RF.

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7. Scientific works

Publications in foreign and Bulgarian publications, which are reserved and indexed in Scopus and Web of Science:

G. Gecheva-Fermendzhieva, R. Radev, M. Marinov. *Herniated disc treatment by Prof. G. Gechev underwater lumbar traction method, of a patient refraining from operative treatment with EMG, proved degeneration of L5-S1 root*. Journal of IMAB, 2019, Oct-Dec, 25(4): 2800-2804; ISSN: 1312-773X; Web of Science

G. Gecheva-Fermendzhieva, R. Radev, M. Marinov. *Balneotherapy in an extremely rare condition – paterson-lowry syndrome*. Journal of IMAB, 2019, Oct-Dec, 25(4): 2805-2811; ISSN: 1312-773X; Web of Science

G. Gecheva-Fermendzhieva. *Rehabilitation of patients after stroke and EMG changes in spastic hemiparetic gait, Wernicke-Mann type*. Journal of IMAB, 2021, SUPPLEMENT 11 SEEC & 31 IMAB, Section Varia; pp. 24-26; e-ISSN: 1312-773X; Web of Science

Participation in foreign scientific forums:

1. 29th Annual Assembly of IMAB 9-12.05.2019 – G.Gecheva – Fermendzhieva, R.Radev. M. Marinov, "Herniated disc treatment by prof. G. Gechev underwater lumbar traction, of a patient refraining from operative treatment with EMG proved degeneration of L5-S1 root"
2. 11th South-East European Conference and 31th Annual Assembly of IMAB 28-31.10.2021 – "Rehabilitation of patients after stroke and EMG changes in spastic hemiparetic gait, Wernicke-Mann type"
3. 13-th SEEC Infections and Cancer and 33th Annual Assembly of IMAB, Belgrade, Serbia, October 2023 – „Improvement of stroke patient's gait after botulinum toxin application "

Participation in Bulgarian scientific forums:

1. National Conference on Physical and Rehabilitation Medicine, online. 25-26.06.2021
2. National Congress of Physical and Rehabilitation Medicine,22-25.09.2022
3. National Conference on Physical and Rehabilitation Medicine, 13-15.10.2023