J Int Acad Phys Ther Res 2018; 9(2): 1447~1454
ISSN 2092-8475

www.iaptr.org
https://doi.org/10.20540/JIAPTR.2018.9.2.1447

Muscle activity in relation to the changes in peripheral nerve conduction velocity in stroke patients: Focus on the dynamic neural mobilization technique

The objective of this study was to investigate the dynamic neural mobilization program on the changes in muscle activity and nerve conduction velocity (NVC) in stroke patients. The participants were sampled and randomly divided into experimental group I (n=12) who underwent arm neural mobilization and experimental group II (n=13) who underwent arm dynamic neural mobilization. As the pretest, peripheral NVC of the radial, median, and ulnar nerves were measured using the Viking Quest; the biceps brachii, brachioradialis, flexor carpi radialis, and extensor carpi radialis activities were measured with sEMG. Each intervention program consisted of 10 trials per set and three sets per session. The intervention programs were performed once daily for four weeks (four days/week). Posttest measurements were taken equally as the pretest measurements. Significant differences in peripheral NVC in all sections of the radial and median nerves and wristbelow elbow and below elbow-above elbow areas of the ulnar nerve, as well as in muscle activity of all muscles except the biceps brachii. These findings indicate that dynamic neural mobilization was effective in increasing peripheral NVC and altering the muscle activity.

Key words: *Dynamic neural mobilization, Never conduction velocity, Nerve Viscoelastic effect, Stroke*

Jeong IL Kang[a], Young Jun Moon[b], Dae Keun Jeong[a], Hyun Choi[c], Joon Su Park[a], Hyun Ho Choi[a]

[a]Sehan University; [b]Jung-Ang Hosipital; [c]Mokpo Mirae Hosipital, Republic of Korea

Received : 12 March 2018
Revised : 03 April 2017
Accepted : 17 April 2017

Address for correspondence
Young Jun Moon, PT, PhD,
Department of Physical Therapy, 13-1, Samil-ro, Samhyang-eup, Muan-gun, Jeonnam, 586-15, Republic of Korea
E-mail: tkfkdgo0328@naver.com
sampled and randomly divided into experimental

INTRODUCTION

Abnormal motor patterns and muscle tension in stroke patients affect the nerve conduction velocity (NVC), a unique characteristic of the nervous system, thereby limiting arm functions and consequently posing heavy restrictions in stroke patients' daily living [1,2]. Therefore, several interventions have been suggested to promote recovery of arm functions in stroke patients. Although these interventions have shown positive outcome in terms of functional recovery, they could not achieve complete recovery in arm functions as functional impairments persisted in the distal areas of the arm [3]. Thus, research is ongoing to develop more effective interventions that promote better recovery of arm functions [4].

Neural mobilization, among many interventions to recover arm function, is a technique that aims to restore the velocity of nerve conduction to the spinal tract through movement while maintaining tension in the neural axis [5]. The efficacy of this method has been already verified in patients with multiple musculoskeletal disorders. It is currently being applied to stroke patients to promote functional recovery for various symptoms [6] and has been found to increase arm range of motion (ROM) and improve neuromuscular flexibility and circulation within the nervous system by increasing the mobilization of the peripheral nervous system in stroke patients [7]. As shown here, neural mobilization applied to the paretic arm may facilitate recovery of muscles and soft tissues in the course [8], which is important for not only muscle strength but also normal functioning of the nervous system. Securing normal ROM and muscle tension through neural mobilization is an essential factor in moving the body through appropriate extension and flexion without limitation [9]. Studies on the application of neural mobilization to stroke patients are in progress, and neural mobilization has a positive effect. But this causes a lot of pain among patients due to sustained tension, and after rehabilitation exercise, the recovery of function slows down because of the problems of mechanoreceptors [10]. Therefore, some have suggested the need to integrate or improve existing rehabilitation techniques to create a new intervention program for a better recovery of arm functions [11]. Based on this, Ha [12] combined elastic band exercise with neural mobilization to develop an efficient home training program, and other studies have integrated dance-like movements to neural mobilization for stroke patients in an attempt to develop more efficient exercise programs for functional recovery [13].

Although multiple interventions promoting functional recovery in stroke patients have produced positive effects, with research still ongoing, there is a need to develop intervention programs to resolve mechanical receptor problems in the distal area that persist even after rehabilitation. Therefore, this study aims to verify the efficacy of the arm dynamic neural mobilization technique, which integrates dynamic arm movements to neural mobilization in the distal area of the paretic arm, by analyzing the changes in muscle activity in relation to the elevated NVC in the paretic arm in stroke patients.

MATERIALS AND METHODS

Subjects

This study was approved by the institutional review board of Sehan University (SH-IRB 2016-12). Twenty-five patients who presented to the M hospital in South Jeolla Province between June and November 2017 were enrolled. The inclusion criteria were as follows: stroke with a diagnosis of hemiplegia from cerebral infarction or cerebral hemorrhage with time from disease onset of less than six months without other neurologic or orthopedic disease history, no limitation in passive ROM on the paretic side arm, no paresthesia on the affected area, no visual or auditory disturbances or aphasia, a Modified Ashworth Scale (MAS) below GⅡ, and a mini-mental state examination-Korean version (MMSE-K) score greater than 24 to understand and follow the investigator's instructions. All enrolled participants understood the purpose of this study and voluntarily participated. The participants' general characteristics are shown in Table 1.

Table 1. General characteristics

Items	Experimentalgroup I (n=12)	Experimentalgroup II (n=13)	p-value
Age	60.4±8.22	58.1±4.14	.634
Height(㎝)	159.31±11.22	165.91±4.62	.432
Weight(㎏)	63.31±5.51	64.11±7.16	.368
MMSE-K(score)	25.20±2.50	26.80±2.26	.329

Measurement Methods

Twenty-five patients with stroke-induced hemiplegia were sampled and randomly divided into experimental group I (n=12) for neural mobilization and experimental group II (n=13) for arm dynamic neural mobilization. As the pretest, the wrist-forearm area of the radial nerve, wrist-elbow and elbow-axilla area of the median nerve, and wrist-below elbow, below elbow-above elbow area, and above elbow-axilla area of the ulnar nerve were measured using the Viking Quest equipment. In addition, the biceps brachii, brachioradialis, flexor carpi radialis, and extensor carpi radialis activities were measured with surface electromyography (sEMG) After administering interventions (10 trials per set and three sets per session) once a day, four days a week for four weeks, posttest measurements were taken equally as the pretest measurements.

Patients were intervened by a physical therapist, who mastered neural mobilization and have over 7 years of clinical experience in Korea, NVC measurement was performed by a medical technologist with over 20 years of clinical experience, and muscular activity was measured by a physical therapist intervening in this study.

2) Measurement tool and method

NVC

NVC was measured with the Viking Quest (Bourgogne, France), with the following settings: high filter 10㎑, low filter 50㎐, sensitivity 2-5㎷/division, stimulation duration 0.2㎳, and stimulation frequency 1㎐. Laboratory temperature was maintained at 26℃. The patients were told to lie on their backs comfortably, and their hands were warmed at 31~34℃ with an infrared heater. After wiping the electrode attachment sites with alcohol, the active electrode was attached to the belly of the brachioradialis using surface attachment stimulation to measure motor NVC of the radial nerve, and the reference electrode was attached to the most distal area from the brachioradialis. For the medial nerve, the active electrode was attached to the belly of the adductor pollicis brevis, and the reference electrode was attached to the tendon, 3cm posterior to the active electrode. Finally, for the ulnar nerve, the active electrode was attached to the belly of the abductor digiti minimi, and the reference electrode was attached to the tendon, 3cm posterior to the active electrode. Ground electrode was attached between the stimulation electrode and active electrode equally in all nerves [12].

Upper limb muscle activity

Arm muscle activity was measured with the4-channel sEMG MP100 (Biopac system, USA), at a sampling rate of 1,000Hz and frequency band-pass filter of 30~450Hz. To minimize skin resistance of sEMG signals, the skin was shaved, exfoliated using a thin sandpaper, and cleaned with an alcohol swab. Two Ag/AgCl surface electrodes were attached to each muscle, parallel to the muscle fibers and in 2cm intervals. The biceps brachii, brachioradialis, flexor carpi radialis, and extensor carpi radialis activities of the paretic arm were measured. sEMG signals were measured while the participants performed maximal grip exercise with shoulders bent about 90° while comfortably sitting on a chair. The average of the three trials of the 6-s interval (after deleting the first and last 2 s) was set as the root mean square (RMS) amplitude during the reference movement. In addition to the reference movement, RMS amplitude during a specific movement was computed by instructing the participants to pick up a cube-shaped tool (2×5) and flip it to the right and repeat the process toward the left for 60 s. sEMG measurement was performed during this time. Three trials were performed, and the average of the data from the middle 40 s (after deleting the first and last 10 s) was set as the RMS amplitude for a specific movement. These muscle activities were normalized by dividing the RMS amplitude during the reference movement by RMS amplitude during a specific movement and multiplying it by 100. A 2-min break was taken equally between trials.

Exercise Methods

In the arm dynamic neural mobilization technique, the therapist dynamically mobilizes the radial nerve by lowering the patient's shoulder toward the closer leg while adducting the glenohumeral joint, extending the elbow joint, and pronating the forearm with the patient in the supine position. The therapist uses a metronome in dynamically overextending the distal area of the arm of the stroke patient, once every 2 s for 20 s. For the dynamic mobilization of the median nerve, the patient is in the supine position with the shoulder joint spread about 90°, elbow joint flexed about 90°, and wrist joint in dorsal flexion. The therapist fixes the patient's shoulder with one hand and abducts the shoulder joint, extends the elbow joint, supinates the forearm, and completely extends the fingers and wrists with the other hand. The therapist uses a metronome in dynamically overextending the distal area of the arm once every 2 s for 20 s. For dynamically mobilizing the ulnar nerve, the patient takes the same postures as that for the mobilization of the median nerve, and the therapist maximally abducts the patient's shoulder, pronates the forearm, and completely extends the fingers and wrist while the patient laterally flexes the neck to the opposite side. Again, a metronome was used to dynamically overextend the distal area of the arm once every 2 s for 20 s.

Arm neural mobilization was performed in the same posture as that for the arm dynamic neural mobilization, but the distal area of the arm was extended for 20 s without dynamic movements.

Data analysis

Data were processed using the Window SPSS 20.0 software. Participants' general characteristics and normality were analyzed with Shapiro−Wilk test. In addition, paired t−test was used to investigate arm NVC and changes of muscle activity within each group. Intergroup differences of arm NVC and changes in muscle activity were analyzed with the ANCOVA, and statistical significance was set at α=.05.

RESULTS

1. Comparison of peripheral NVC and muscle activity changes in the arm in experimental group I

We analyzed the NVC of the radial nerve, median nerve, and ulnar nerve for experimental group I and found that there were significant differences of NVC in the wrist−elbow area (p〈.05) and elbow−axilla area (p〈.01) of the median nerve and wrist−below elbow area (p〈.05) of the ulnar nerve 〈Table 2〉. Regarding muscle activity, there were only significant differences in the flexor carpi radialis (p〈.05) and extensor carpi radialis (p〈.05)〈Table 2〉.

2. Comparison of peripheral NVC and muscle activity changes in the arm in experimental group II

There were significant differences of NVC in the wrist−forearm area (p〈.05) of the radial nerve, wrist−elbow area (p〈.01) and elbow−axilla area (p〈.05) of the median nerve, and wrist−below elbow area (p〈.001) and below elbow−above elbow area (p〈.01) in the ulnar nerve 〈Table 3〉 in experimental group II. Regarding muscle activity, there were significant differences only in the brachioradialis (p〈.001), flexor carpi radialis (p〈.001), and extensor carpi radialis (p〈.001)〈Table 3〉.

3. Comparison of peripheral NVC and muscle activity changes in the arm between experimental group I and experimental group II

The two groups significantly differed in NVC in the wrist−forearm area of the radial nerve (p〈.001), wrist−elbow area (p〈.05) and elbow−axilla area (p〈.01) of the median nerve, and wrist−below elbow area (p〈.001) and below elbow−above elbow area (p〈.05) of the ulnar nerve 〈Table 4〉. In addition, the two groups also significantly differed in brachioradialis (p〈.01), flexor carpi radialis (p〈.05), and extensor carpi radialis (p〈.001) activities 〈Table 4〉.

Table 2. Comparisons of changes in NCV and %RVC for Experimental group I

Items			Experimental group I (n=12)		t	p'
			Pre−test	Post−test		
NCV(㎧)	Radial nerve	wrist−forearm	49.43±1.91	50±1.24	−1.295	.218
	Median nerve	wrist−elbow	51.36±1.45	52.64±1.28	−2.590	.022*
		elbow−axilla	55.86±5.1	57.29±3.79	−3.069	.009**
	Ulnar nerve	wrist−below elbow	57.79±3.42	60.14±1.92	−2.300	.039*
		below elbow−above elbow	54.64±3.13	56.36±3.91	−1.949	.073
		above elbow−axilla	53.5±2.77	55.79±2.52	−1.867	.085
%RVC	biceps brachii		37.91±5.49	35.08±4.1	1.651	.123
	brachioradialis		79.38±4.06	80.39±4.58	−1.373	.193
	flexor carpi radialis		82.02±2.99	79.17±3.07	2.232	.044*
	extensor carpi radialis		97.54±1.66	97.49±3.52	−2.409	.032*

'Paired t−test

*p〈.05, **p〈.01

NCV: Nerve conduction velocity, %RVC: %Reference voluntary contraction

Table 3. Comparisons of changes in NCV and %RVC for Experimental group Ⅱ

Items			Experimental group Ⅱ (n=13)		t	p'
			Pre–test	Post–test		
NCV(㎧)	Radial nerve	wrist–forearm	50.57±2.21	53±1.57	–2.858	.013*
	Median nerve	wrist–elbow	50.71±1.73	54.43±2.38	–3.951	.002**
		elbow–axilla	57.29±5.08	61.86±4.31	–3.011	.01*
	Ulnar nerve	wrist–below elbow	58.57±1.99	64.43±2.28	–25.352	.000***
		below elbow–above elbow	56±2.66	61.43±4.86	–3.821	.002**
		above elbow–axilla	53.5±2.79	54.64±2.76	–0.873	.398
%RVC	biceps brachii		37.21±2.41	36.4±3.16	0.855	.408
	brachioradialis		77.71±4.19	83.22±2.97	–5.790	.000***
	flexor carpi radialis		88.64±2.38	79.97±2.85	7.977	.000***
	extensor carpi radialis		93.98±2.47	104.39±2.47	–12.863	.000***

'Paired t–test
*p〈.05, **p〈.01, ***p〈.001
NCV: Nerve conduction velocity, %RVC: %Reference voluntary contraction

Table 4. Comparison of changes in NCV and %RVC for between groups

Items			Groups	Pre–test	Post–test	F	p'
NCV(㎧)	Radial nerve	wrist–forearm	E– Ⅰ	49.43±1.91	50±1.24	28.386	.000***
			E–Ⅱ	50.57±2.21	53±1.57		
	Median nerve	wrist–elbow	E– Ⅰ	51.36±1.45	52.64±1.28	4.732	.039*
			E–Ⅱ	50.71±1.73	54.43±2.38		
		elbow–axilla	E– Ⅰ	55.86±5.1	57.29±3.79	9.418	.005**
			E–Ⅱ	57.29±5.08	61.86±4.31		
	Ulnar nerve	wrist–below elbow	E– Ⅰ	57.79±3.42	60.14±1.92	28.781	.000***
			E–Ⅱ	58.57±1.99	64.43±2.28		
		below elbow–above elbow	E– Ⅰ	54.64±3.13	56.36±3.91	7.062	.014*
			E–Ⅱ	56±2.66	61.43±4.86		
		above elbow–axilla	E– Ⅰ	53.5±2.77	55.79±2.52	1.747	.198
			E–Ⅱ	53.5±2.79	54.64±2.76		
%RVC	biceps brachii		E– Ⅰ	37.91±5.49	35.08±4.1	.999	.327
			E–Ⅱ	37.21±2.41	36.4±3.16		
	brachioradialis		E– Ⅰ	79.38±4.06	80.39±4.58	12.369	.002**
			E–Ⅱ	77.71±4.19	83.22±2.97		
	flexor carpi radialis		E– Ⅰ	82.02±2.99	79.17±3.07	3.314	.038*
			E–Ⅱ	88.64±2.38	79.97±2.85		
	extensor carpi radialis		E– Ⅰ	97.54±1.66	97.49±3.52	33.591	.000***
			E–Ⅱ	93.98±2.47	104.39±2.47		

*p〈.05, **p〈.01, ***p〈.001
NCV: Nerve conduction velocity, %RVC: %Reference voluntary contraction

DISCUSSION

For stroke patients, recovering arm functions means to restore the ability to move the arm in a normal trajectory from the starting position to the target when performing a task and the ability to grasp, an action performed by the fingers while the arm is moving [14]. However, stroke patients have difficulty in performing such tasks even after undergoing interventions due to the irregular muscle activities in the distal area of the arm caused by mechanical receptor problems, requiring the development of continuous exercise programs to resolve this issue [15]. In response to such need, this study discusses how the arm dynamic neural mobilization technique applied in the paretic arm of stroke patients affects muscle activities in the distal areas of the arm through changes in NVC.

Stroke patients have slower NVC due to their nervous system structure and muscle shortening caused by a variety of factors [16]. In a study comparing the peripheral NVC between the normal and paretic arms, Bonifer and Anderson [17] found that the peripheral NVC in the paretic arm was markedly slower, based on which they emphasized the importance of neural mobilization in rehabilitation programs. Neural mobilization is a technique that has been used on patients with musculoskeletal disorders to restore damaged tissue functions by indirectly moving or extending the nerve tissues through joint movement [6] and is currently used also for patients with peripheral neuropathies or central nervous system disease, such as stroke, to promote functional recovery [13]. Studies that applied neural mobilization on stroke patients reported that the patients showed increased peripheral NVC as a result of elevated adaptability of nerve tissues [18] and better arm task performance owing to the restoration of balanced muscle activity, where increased muscle activities are reduced and weakened muscle activities are elevated [19]. These findings suggest that elevated peripheral NVC normalizes muscle tension, thereby effectively improving arm functions [13]. This study also applied neural mobilization on the arm and measured NVC and found that there were significant changes in NVC in the wrist–elbow area and elbow–axilla area of the median nerve ($p<.05$ and $p<.01$, respectively) and wrist–below elbow area of the ulnar nerve ($p<.05$). Neural mobilization also significantly altered activity of the flexor carpi radialis and extensor carpi radialis ($p<.05$). In the group that underwent arm dynamic neural mobilization, there were significant changes in NVC in the wrist–forearm area of the radial nerve ($p<.05$), wrist–elbow area and elbow–axilla area of the median nerve ($p<.05$ and $p<.01$, respectively), and wrist–below elbow area and below elbow–above elbow area of the ulnar nerve ($p<.001$). Regarding muscle activity, there were significant changes in all muscles except for the biceps brachii ($p<.001$), all of which support previous findings that neural and dynamic neural mobilization brings about positive changes in surrounding muscle activities by increasing peripheral NVC.

The ultimate goal of arm rehabilitation for stroke patients is to restore the functions such as grasping and hand flipping using synergistic action of the fingers [20]. However, stroke patients have instable hand functions even after exercise, as the recovery of hand's fine motor skills is slow due to mechanical receptor problems in the distal areas of the arm [10,21]. To address this issue, this study has suggested the need to improve existing exercise programs or develop new ones and verify their effectiveness on patients [22]. Thus, Ha [12] integrated the elastic band exercise to the existing arm neural mobilization technique and reported that this is a more efficient exercise method, as supported by the increased peripheral NVC in a wider area of the median nerve in the elastic band and neural mobilization group compared to that in the neural mobilization group. Kang et al. [13] reported that rhythmic neural mobilization, which integrates dance–like movement to the existing neural mobilization technique, leads to elevated peripheral NVC in greater areas compared to that resulting from neural mobilization. As shown here, there are ongoing studies to develop new rehabilitation programs by integrating new tools and techniques to existing programs. As a part of such effort, this study compared the changes in NVC resulting from the conventional neural and dynamic neural mobilization of the arm. In short, we found that arm dynamic neural mobilization is more effective than arm neural mobilization, as supported by the significant differences of NVC in the wrist–forearm area of the radial nerve, all sections of the median nerve, and the wrist–below elbow area and below elbow–above elbow area ($p<.05$, $p<.01$, and $p<.001$, respectively), as well as significant differences of muscle activity in the brachioradialis, flexor carpi radialis, and extensor carpi radialis ($p<.05$, $p<.01$, and $p<.001$, respectively). These results suggest that dynamic movement induced by the therapist is more effective in increasing peripheral NVC and improving muscle activities by extending the time patients need to adapt to the external force and helps tissue recovery by facilitating appropriate muscle contraction and relaxation [23]. In a similar study by Kang et al. [13] rhythmic arm neural mobilization led to better viscoelasticity of the peripheral nervous system, thereby increasing peripheral NVC in a wider area. Further, neural mobilization activates the muscle spindles and Golgi tendon organ [24], but adding dynamic movement to the technique is speculated to lead to more effective activation of these components, more efficiently inducing changes of muscle activities. This study found that arm dynamic neural mobilization is an intervention that effectively alters arm muscle activity by increasing NVC in more areas through stimulation of mechanical receptors and efficient activation of the muscle spindles and Golgi tendon organ. Therefore, we believe that arm dynamic neural mobilization would be useful for promoting arm functional recovery in stroke patients and also suggest future studies to continue investigating the effects of dynamic neural mobilization on not only stroke patients but also other patients with various central nervous system diseases.

ACKNOWLEDGEMENT

This study was supported by the Sehan University Research Fund in 2018.

REFERENCES

1. Kwon YH, Kim CS. Comparison of Motor Function andSkill between Stroke Patients with Cerebellar and NoncerebellarLesion in Sub-acute Stage. J Korean Soc Phys Ther2012;24(6):423-7.
2. Kim BY, Choi WH. The effects of interferential cuttent therapy on spasticity, range of motion, and balance ability in stroke patient. J Kor Soc Phys Ther 2013; 25(4):187-194.
3. de los Reyes-Guzmán A, Dimbwadyo-Terrer I, Trincado-Alonso F, et al. Quantitative assessment based on kinematic measures of functional impairments during upper extremity movements: A review. Clinical Biomechanics2014;29(7): 719-727.
4. Koh EK, Jung DY. Effects of mulligan's mobilization with movement on talofibular interval in subjects with chronic ankle instability. J Kor Phys Ther 2016;28(5):303-7.
5. de Oliverira Junior HF, Teixeira ÁH. Mobilização do sistema nervoso: avaliação e tratamento. Fisioter mov 2007;20(3):41-53.
6. Nery dosSantos AC, Gusmão deGoes AC, Lago RMV, et al. Neural mobilization as a therapeutic option in the treatment of stroke. Man Ther 2016;14(310):1-4.
7. Scrimshaw SV, Maher CG. Randomized controlled trial of neural mobilization after spinal surgery. Spine2001; 26(24): 2647-2652.
8. Koshy JC, Agrawal NA, Seruya M, et al.Nerve Transfer versus Interpositional Nerve Graft Reconstruction for Posttraumatic, Isolated Axillary Nerve Injuries: A Systematic Review. Plastic and reconstructive surgery2017;140(5): 953-960.
9. Butler DS, Jones MA. Mobilization of the nervous system. Elsevier health sciences1991;1-44
10. Boyd BS, Wanek L, Gray AT, et al. Mechanosensitivity during lower extremity neurodynamic testing is diminished in individuals with type 2 Diabetes Mellitus and peripheral neuropathy: a cross sectional study. BMC Neurol 2010;10(75):1-14.
11. Robson N, Faller IIKJ, Ahir V, et al. Creating a virtual Perception for upper limb rehabilitation. Stroke 2017;11(4):152-157.
12. Ha MS. The effects of median nerve self-mobilization on shoulder depression and wrist extension. Silla University. Dissertation of Master's Degree, 2013.
13. Kang JI, Moon YJ, Jeong DK, et al. The Effect of Rhythmic Neurodynamic on the Upper Extremity Nerve Conduction Velocity and the Function for Stroke Patients. The Journal of Korean Physical Therapy2017;29(4): 169-174.
14. Msengana Z. The outcomes for upper limb mobility and personal management during the three months after onset of stroke in patients attending occupational therapy (Doctoral dissertation),2017.
15. Lang CE, Bland MD, Bailey RR, et al. Assessment of upper extremity impairment, function, and activity after stroke: foundations for clinical decision making. J Hand Ther 2013;26(2):104-114.
16. Nee RJ, Butler D. Management of peripheral neuropathic pain: integrating neurobiology, neurodynamics, and clinical evidence. Phys Ther Sport 2006;7(1):36-49.
17. Bonifer N, Anderson KM. Application of constraint-induced movement therapy for an individual with severe chronic upper-extremity hemiplegia. Physical therapy2003; 83(4): 384-398.
18. Wolny T, Saulicz E, Myśliwiec A, et al. Effectiveness of neuromobilisation in upper limb

discriminatory sense rehabilitation in late-stage post-stroke patients. Physikalische Medizin, Rehabilitationsmedizin, Kurortmedizin2014; 24(01): 42-47.

19. Godoi J, Kerppers II, Rossi LP, et al. Electromyographic analysis of biceps brachii muscle following neural mobilization in patients with stroke. Electromyogr Clin Neurophysiol 2010;50(1):55-60.
20. Rosales RL, Kanovsky P, Fernandez HH. What's the "catch" in upper-limb post-stroke spasticity: expanding the role of botulinum toxin applications. Parkinsonism Relat Disord 2011;17(1):3-10.
21. Hara Y. Rehabilitation with functional electrical stimulation in stroke patients. Int J Phys Med Rehabil2013; 1(147): 2.
22. Nussbaum EL, Houghton P, Anthony J, et al. Neuromuscular Electrical Stimulation for Treatment of Muscle Impairment: Critical Review and Recommendations for Clinical Practice. Physiotherapy Canada2017;69(5): 1-76.
23. Eaves DL, Behmer LP, Vogt S, et al. EEG and behavioural correlates of different forms of motor imagery during action observation in rhythmical actions. Brain and cognition2016; 106: 90-103.
24. Pack JW. The effect of the upper limb soft tissue and nerve mobilization on functional recovery in hemiplegic patients after CVA. University. Taegu Dissertation of Master's Degree, 2001.