

The Effect of Vibratory Stimulation on Tissue Compliance and Muscle Activity in Elbow Flexor Spasticity

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Abstract. [Purpose] This study investigated the effect of vibratory stimulation on tissue compliance and muscle activity in stroke patients with elbow flexor spasticity. [Subjects and Methods] Twenty patients who were grade 2 on the Modified Ashworth Scale (MAS) were evaluated before and after vibratory stimulation. This evaluation was done using MAS (change of clinical characteristic), a myotonometer (change in muscle tissue compliance), and surface electromyography (sEMG) (change in muscle activity). [Results] MAS results showed significant decreases immediately and three weeks after the start of vibratory stimulation. Tissue compliance significantly increased immediately (0.75, 1, and 1.25 kg) and three weeks (0.5, 0.75, 1, 1.25, and 1.5 kg) after the start of vibratory stimulation, and muscle tone decreased. Muscle activity significantly increased immediately (1 and 1.25 kg) and three weeks (0.75, 1, 1.25, and 1.5 kg) after the start of vibratory stimulation. [Conclusion] Using a myotonometer and sEMG, we demonstrated that vibratory stimulation was an effective form of therapeutic stimulation. Vibratory stimulation can be used as a non-pharmacological therapy for the neurorehabilitation of patients with spasticity.

Key words: Vibratory stimulation, Myotonometer, Tissue compliance

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INTRODUCTION

Spasticity is a general symptom of the upper motor nervous system¹⁾. In 1980, Lance described spasticity as a motor abnormality that is characterized by velocity-dependent resistance during the passive movement of the limbs in CNS injured patients²⁾. Quadriplegia and muscular weakness are associated with spasticity and also affect motor function. Patients with spasticity experience serious deterioration in quality of life and social participation³⁾. Thus, various clinical methods to control spasticity are being attempted.

Vibratory stimulation is a useful tool for reducing the spasticity of stroke patients^{4, 5)}, but studies of its effects are insufficient. Physical therapists must accurately know the characteristics of spasticity and the correlation between the level of spasticity and involuntary movement^{6, 7)}. Furthermore, an accurate evaluation of spasticity is critical for establishing therapy plans and judging the results.

The recent SPASM Project in Europe suggested that mechanical elements of soft tissues (muscles, tendons, ligaments) are important causes of spasticity⁸⁾. Therefore, it is important to understand the changes in soft tissues when evaluating spasticity. A myotonometer that can accurately assess the elastic characteristics of tissues was recently developed. This device is useful for objectively assessing the degree of tissue compliance by computerizing the degree

of tissue displacement per force applied to the muscles⁹⁾. The purpose of this study was to measure and document the effects of vibratory stimulation on elbow flexor spasticity through the changes in muscular characteristics (tissue compliance and muscle activity) using a myotonometer and sEMG.

SUBJECTS AND METHODS

Subjects

The subjects of this study were 20 stroke patients in a rehabilitation hospital. The subjects were recruited from among those who were at least six months after the onset of stroke, were grade 2 on the MAS, on which they showed a noticeable increase in spasticity but could move their elbow joint¹⁰⁾, had no pathological findings in the musculoskeletal system of the elbow, could understand and follow the directions of the experimenter, and had no history of treatment with botulinum toxin, phenol, or alcohol injections. Each subject voluntarily consented to participation in this study. Data collection was started after approval was received from the University Institutional Review Board of Dongshin University. The general characteristics of the subjects are listed in Table 1.

Table 1. Characteristics of study participants

	MAS Grade 2 (n=20)
Age (years)	51.25 ± 5.69
Sex (male/female)	8/12
Time since onset (months)	37.8 ± 7.67
Affected side (right/left)	8/12
Cause (hemorrhage/ischemic)	7/13

(M ± SD) MAS, Modified Ashworth Scale

Methods

The vibration stimulator (Thrive MD-01, Thrive Co., Ltd., Osaka, Japan) has an amplitude of 1.0 mm and a frequency of 91 Hz, and its head (diameter=5 cm) is covered with rubber¹¹⁾. The subjects received vibratory stimulation to their biceps and triceps brachii muscle bellies simultaneously in a supine position for 20 min once a day five times a week for three weeks.

Three assessments were made: Step 1, before vibratory stimulation; Step 2, immediately after vibratory stimulation; and Step 3, after three weeks of vibratory stimulations. The clinical assessment of spasticity was performed using MAS by three physical therapists who had at least five years of clinical experience. For statistics, the MAS G0, G1, G1+, G2, G3, and G4 scores were given values of 0, 1, 2, 3, 4, and 5¹²⁾. To minimize the effect of the measurer, the myotonometer and sEMG results were not given to the MAS measurer.

The differences in muscular tissue compliance were measured with Myotonometer® (Neurogenic Technologies, Inc., Missoula, USA)⁹⁾. myotonometer is a patented muscle compliance measuring device that has been approved as a medical electronic device by the FDA¹³⁾. The dual probes record the changing potential of tissues (± 0.1 mm) at 8 levels of force (0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2.0 kg).⁹⁾ The changes in muscle activity were measured using BTS Pocket EMG (BTS Co. Milan, Italy). The sampling rate of the signals was set to 1000 Hz and the filtering range was set to 20–500 Hz. Each subject was seated in an armchair with their elbows bent at 90° and their forearms supinated in order to relax the upper limbs. Then, the biceps brachii muscle of the affected side was measured¹⁴⁾. To measure the tone compliance changes of the biceps brachii muscle, Myotonometer was used to collect data at relaxation and maximal voluntary contraction, and sEMG was used to collect data at maximal voluntary contraction. The measurements were made three times at both relaxation and maximal voluntary contraction.

The probe of Myotonometer was placed about 2 cm from the electromyogram electrode on the biceps brachii muscle¹³⁾. Myotonometer collected data in eight steps at one second intervals⁹⁾. The EMG data collection interval was also set to one second to correspond with the data collection time of Myotonometer. One measurer collected Myotonometer data and another measurer collected the sEMG data. Data collection by each measurer was hidden from the other measurers. During the contraction timing, the subject was instructed to make a maximal voluntary contraction

of the elbow flexor. To restrict the movement of the upper limb, the wrist was fixed with a strap to apply resistance to the wrist. A portable dynamometer® (Jamar, Clifton, USA) was placed at the periphery of the forearm to measure the maximal voluntary contraction of the upper limb. The muscle activity was analyzed by standardizing the EMG amplitude (root-mean-square) collected for eight seconds at maximal voluntary contraction in each measurement step. The means and standard deviations of all the data of this study were calculated using the Windows version of SPSS/PC 12.0. Repeated measures ANOVA was conducted for statistical analysis of all measurement data. When a significant difference was found, a contrast test was performed. Statistical significance was accepted for values of ≤ 0.05 .

RESULTS

The MAS score of the biceps brachii muscle that was measured immediately after vibratory stimulation was lower than that of the baseline, which was measured before vibratory stimulation ($p < 0.05$). After three weeks, the MAS score had considerably decreased from the baseline measured before vibratory stimulation ($p < 0.001$) (Table 2).

The tissue compliance at relaxation, which was measured in 8 steps (0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2.0 kg), immediately after vibratory stimulation significantly increased in the range of 0.75 kg to 1.25 kg compared to the baseline measured before the vibratory stimulation ($p < 0.05$). Three weeks after the start of vibratory stimulation, it had significantly increased in the range of 0.5 kg to 1.5 kg compared to pre-stimulation ($p < 0.05$). However, the tissue compliance at maximal voluntary contraction did not change significantly compared to the baseline (Table 3).

The muscle activity at maximal voluntary contraction at the 8 Myotonometer steps immediately after vibratory stimulation significantly increased from the muscle activity before vibratory stimulation in the range from 1.0 kg to 1.25 kg ($p < 0.05$). After three weeks, the muscle activity significantly increased from the muscle activity measured before vibratory stimulation in the range from 0.75 kg to 1.5 kg ($p < 0.05$) (Table 4).

DISCUSSION

Neurologic injuries primarily damage the neuromuscular system and affect the number, type, and discharge frequency of the motor neurons that are recruited for functional motions. This generates a secondary impairment in that the ability to exert mechanical force through muscle contraction is hindered¹⁵⁾. This secondary impairment brings about changes in muscle tone, compliance, and muscle fibers. Therefore, accurate evaluation of the spasticity and spastic condition of muscles is essential for understanding the condition of patients with neurologic injuries, and for evaluating the therapeutic intervention¹⁶⁾.

Among the therapies for spasticity, vibratory stimulation of the somatic senses is arousing increasing interest these days. Murillo et al. reported that spasticity decreased after vibratory stimulation of rectus femoris muscles that had

Table 2. MAS changes induced by vibratory stimulation

	Time of Examination		
	Pre	Immediately after	Post three weeks
MAS	3.48 ± 0.2	3.33 ± 0.2*	2.98 ± 0.58**

(M ± SD) The mean and standard deviation show the changes in MAS caused by vibratory stimulation. Repeated measures ANOVA was performed (pre-immediately after *; $p < 0.05$, pre-post three weeks **; $p < 0.001$).

hitherto shown hyperexcitability or hyperreflexia of the stretch reflex in patients with spinal cord injury¹⁷). Shira-hashii et al. reported that the functions of paralyzed shoulder and fingers in stroke patients improved when functional vibratory stimulation was applied¹⁸). Two studies report a mitigation of spasticity using clinical or neurophysiological evaluations^{18, 19}). However, the development of Myotonometer has enabled a new approach that allows quantitative measurement of the mechanical elements in the soft tissues of spastic muscles^{9, 20}). This study used Myotonometer to measure the changes in tissue compliance at 8 forces that were applied in the longitudinal and perpendicular directions of the muscles after applying vibratory stimulation to spastic muscles. The effects of tissue compliance changes at the 8

steps on the muscle activity were also measured with sEMG.

MAS showed a more significant decrease of spasticity over time than immediately after vibratory stimulation (Table 2). Manganotti and Amelio explained this was due to the effects of mechanical vibratory stimulation and spinal cord excitability²¹). Noma et al. suggested that decreasing spasticity was caused by a decrease in F-wave amplitude¹⁹). Therefore, a probable explanation for the spasticity decrease seen in our study is that the vibratory stimulation decreased the excitability of the α -motor neurons through the activation of presynaptic inhibition.

Marconi et al. reported that long-term application of vibratory stimulation to stroke patients with upper limb spasticity resulted in spasticity decrease and motor map areas increase, and emphasized the importance of long-term stimulation¹⁰). In the present study, tissue compliance at relaxation showed significant increases in 3 steps from 0.75 kg to 1.25 kg immediately after vibratory stimulation, and in 5 steps from 0.5 kg to 1.5 kg after vibratory stimulation for three weeks, indicating the importance of long-term stimulation. However, tissue compliance at contraction was similar to the baseline before vibratory stimulation (Table 3). Leonard et al. compared the tissue compliances of spastic and normal muscles with Myotonometer. They found no significance difference at relaxation and a significant difference at contraction, which is the opposite of the findings of our

Table 3. Tissue compliance changes induced by vibratory stimulation (mm)

	Force(kg)	0.25	0.5	0.75	1	1.25	1.5	1.75	2
Rest									
Pre		3.55 ± 0.44	5.48 ± 0.54	5.98 ± 0.31	6.98 ± 0.43	7.43 ± 0.41	8.22 ± 0.42	8.54 ± 0.95	8.73 ± 1.13
Immediately after		3.66 ± 0.44	5.56 ± 0.58	6.07 ± 0.35 [#]	7.11 ± 0.34 [#]	7.60 ± 0.44 [#]	8.30 ± 0.54	8.67 ± 1.00	8.59 ± 1.04
Post three weeks		3.70 ± 0.42	5.67 ± 0.53*	6.13 ± 0.33*	7.15 ± 0.26*	7.64 ± 0.44*	8.37 ± 0.52*	8.64 ± 0.94	8.65 ± 0.56
Contracted									
Pre		2.13 ± 0.76	3.02 ± 0.97	3.95 ± 0.77	4.34 ± 0.80	4.94 ± 0.80	5.33 ± 0.88	6.00 ± 1.03	6.26 ± 1.06
Immediately after		2.27 ± 0.65	3.15 ± 0.94	3.98 ± 0.54	4.42 ± 0.58	4.79 ± 0.50	5.13 ± 0.95	5.78 ± 0.88	6.09 ± 0.55
Post three weeks		2.23 ± 0.73	3.06 ± 0.86	3.93 ± 0.78	4.30 ± 0.74	4.86 ± 0.52	5.25 ± 0.61	5.91 ± 0.78	6.11 ± 0.71

This table shows the mean ± standard deviation of tissue potentials at the eight steps during relaxation and contraction of Myotonometer measurement. Repeated measures ANOVA was performed (pre-immediately after [#]; $p < 0.05$, pre-post three weeks *; $p < 0.05$).

Table 4. Muscle activity changes induced by vibratory stimulation (μ V)

Force(kg)	Time of Examination		
	Pre	Immediately after	Post three weeks
0.25	22.79 ± 0.61	22.88 ± 0.58	22.98 ± 0.91
0.5	22.70 ± 0.78	22.98 ± 0.98	22.96 ± 1.18
0.75	23.23 ± 0.40	23.42 ± 0.79	23.57 ± 0.58*
1	24.15 ± 0.35	24.51 ± 0.55 [#]	24.54 ± 0.52*
1.25	24.62 ± 0.38	25.01 ± 0.46 [#]	25.08 ± 0.79*
1.5	23.24 ± 0.40	23.36 ± 0.51	23.72 ± 0.58*
1.75	23.54 ± 0.52	23.63 ± 0.54	23.64 ± 0.45
2	23.04 ± 0.46	23.00 ± 0.61	23.21 ± 0.46

The mean values show the muscle activity changes in the biceps brachii muscle before, immediately after, and after three weeks of vibratory stimulation. Repeated measures ANOVA was performed (pre-immediately after [#]; $p < 0.05$, pre-post three weeks *; $p < 0.05$).

study²²⁾. The reason for this seems to be that vibratory stimulation decreases the stiffness of spastic muscles at relaxation. Long-term repetitive application of vibratory stimulation would increase the tissue compliance at contraction, and the result would be similar to that of Leonard et al.²²⁾. However, regarding the correlation between MAS and Myotonometer, the highest correlations were found in the mid-force range, similar to the result of our study²²⁾.

Leonard et al. examined the correlation between the changes of tissue compliance and muscle activity in 8-step contractions with Myotonometer with normal people as subjects. They found that the correlation coefficient ranged from -0.57 to -0.70 (moderate to good ranges) and the results were significant in 7 of the 8 steps (0.25 and 0.75 to 2 kg)⁹⁾. Muscle activity at relaxation was measured to examine the effects of tissue compliance change at each step of muscle recruitment ability. A significant increase in muscle activity was found at the two steps of 1 kg and 1.25 kg immediately after vibratory stimulation and at the four steps from 0.75 kg to 1.50 kg three weeks after the start of vibratory stimulation compared to the baseline (Table 4). The steps at which muscle activity increased nearly agreed with the steps at which the tissue compliance changed significantly during relaxation. In other words, the decrease of the muscle tone of spastic muscles at relaxation had a greater effect on the increase of muscle activity than the decrease of muscle tone at contraction. It seems that the vibratory stimulation decreased the muscle tone at relaxation and changed the muscle fibers and sarcomeres to the optimal resting lengths at which active force can be generated, thus improving the muscle recruitment ability.²³⁾

Muscles work through contraction and relaxation, but muscle activity changes have been evaluated during contraction in most cases until now. This study showed that as the tissue compliance of spastic muscles at relaxation increased, the muscle tone decreased and the muscle activity increased. Therefore, we need an overall evaluation of spastic muscles, including changes during relaxation as well as during contraction. The findings of this study suggest that vibratory stimulation can be used as a non-pharmacological therapy for the neurorehabilitation of patients with spasticity.

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