

Changes in Electrophysiologic Response during Repeated Contraction Training of the Tibialis Anterior

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Abstract. [Purpose] This study examined the changes in the electrophysiologic response of the tibialis anterior during repeated contraction training. [Methods] We recruited 16 normal adult women without musculoskeletal or neurological disorders for this research. They were divided into an electrical stimulation training group and an electrical/voluntary group. and for electrical stimulation analysis at the 5th, 10th, 15th, 20th, 25th and 30th contraction time electrical stimulations. Maximum voluntary contraction for 6 sec followed by a rest break of 3 sec was performed, repeatedly. The non-dominant tibialis anterior was measured using electromyography and a dynamometer. [Results] MVIC (maximal voluntary isometric contraction), RMS (root mean square), IEMG (intergrated electromyograms) and MDF (median frequency) showed no statistically significant differences in interaction between contraction time and group or main effects between groups, but changes in the main effect of contraction time were significantly different between the groups. The electrical stimulation training group showed a significant difference after 15, 20, 25, and 30 stimulations compared to the first contraction. Group combining voluntary exercise and electrical stimulation showed significant differences after 15, 20, 25, and 30 stimulations compared to the first contraction. [Conclusion] There was decline in electrophysiologic response after repeated contraction training of the tibialis anterior by electrical stimulation and by electrical stimulation and voluntary repeated contraction training and timing that significant decrease was found by the number of repeated contraction trainings of MVIC, RMS, IEMG, and MDF was different.

Key words: MVIC, RMS, Median frequency

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INTRODUCTION

Balance control of gait is achieved by coordination of the body and lower extremity muscles which keep the center of gravity of the body within the base of support and minimize sway¹⁾. The tibialis anterior of the lower extremity generates the most effective and powerful dorsiflexion, because the tendon is distant from the axis of the ankle joint and the tibialis anterior causes ankle inversion across the subtalar joint and the transverse tarsal joint together with the tibialis posterior muscle, which is an antagonistic muscle behind the calf²⁾.

A recent study of treadmill gait training for stroke patients reported that there were significant differences in the activity of the tibialis anterior³⁾. Similarly, Reynard et al.⁴⁾ reported foot inversion in gait by stroke patients was caused by the imbalance of the tibialis anterior. In particular, the lack of lower extremity exercise ability affected walking ability and balance, and increased the risk of falling⁵⁾.

It was reported that functional electrical stimulation training for stroke patients resulted in a great change in the muscle length of the tibialis anterior and gastrocnemius, provided functional exercise control through the effective gait cycle, and generated proper responses to environmental changes and several tasks⁶⁾. A study by Kim⁷⁾, who conducted functional electrical stimulation training with stroke patients, measured muscle fatigue and muscle activity of subjects before and after training. Kim⁷⁾ reported that there were significant differences in gait cycle, muscle fatigue and muscle activity after training. Similarly, Duclay and Martin⁸⁾ measured the tibialis anterior and soleus in the standing and prone positions, and the soleus showed a significant difference after electrical stimulation with a larger the moment in the standing position while the moment of the tibialis anterior showed no significant difference.

Kawakami et al.⁹⁾, who used repeated contraction training to measure the electrophysiologic response, reported that conducting maximal isometric repeated contraction of the

triceps surae in the extension position and knee flexion of 90 degrees resulted in a significant difference in maximum torque. Kim¹⁰⁾ reported that muscle activity around the waist after repeated lift training was high and in particular, the muscle activity of the left rectus abdominis was high.

Many electrophysiologic studies of the tibialis anterior, triceps surae and quadriceps femoris have been reported. In particular, there have been many studies of the function of the tibialis anterior, but electrophysiologic studies of local contraction training are lacking. Therefore, this study examined changes in the electrophysiologic response of the tibialis anterior during repeated contraction training.

SUBJECTS AND METHODS

This study recruited 16 healthy adult woman volunteers. Those who had musculoskeletal or neurological disorders, an athletic career, experience of muscular strength training in the last six months, congenital anomalies, were taking medication for lower limb muscle strength, had exercise disorder or skin diseases, or physical and chemical factors which might have affected the experiment were excluded.

The average age of subjects was 21.8 ± 0.8 years old, their average weight was 52.8 ± 3.2 kg, and their average height was 161.6 ± 4.1 cm. The 16 subjects were divided randomly into two groups: an electrical stimulation training group, 8 subjects, and a voluntary/electrical stimulation training group, 8 subjects. Before the experiment, subjects were given an explanation about the whole process of the experiment and the research was conducted after obtaining the subjects' consent to participation in the experiment.

Subjects relaxed for 20 min before the experiment. The temperature of the laboratory was kept at $25\text{--}27^\circ\text{C}$, and the humidity at 60–70%; and noise which might have disturbed the experiment was controlled. The measurements were made on the non-dominant leg to maximize the muscular contraction effects of the tibialis anterior.

Electrical stimulation was delivered via transcutaneous electrical nerve stimulation (Dyna tens 301, Daeyang Medical System, Korea). Subjects were asked to sit down and straighten their legs and put their ankles in the neutral position. The size of the disposable adhesive electrodes used in the experiment was 5×5 cm, and one of two electrodes was attached to the proximal tibialis anterior and the other to the distal tibialis anterior. Electrical stimulus of maximal tolerable intensity (MTI) was delivered to prevent attenuation from repeated muscle contraction training and to achieve maximum stimulation effect over the whole training period. A square wave with a frequency of 50 Hz was used with an pulsed time, 3 sec of energizing cycles, power cut of 1 sec, and rise up time of $0.5 \times$ sec. We measured electrical stimulation of 5, 10, 15, 20, 25 and 30 times maximal voluntary isometric contraction for 6 sec with a rest break of 3 sec after.

A dynamometer (K-DFX-200, Chatillon, USA) was used to measure maximal voluntary isometric contraction. Subjects were asked to sit down, straighten their legs, and put their ankles in the neutral positions before measurement with the dynamometer. They were asked to fold their arms.

Maximal voluntary isometric contraction was conducted three times and the maximum value was used in the analysis. Electrical stimulation was not applied to 5, 10, 15, 20, 25 and 30 contraction times of total 30 repeated contractions and they were asked to make maximal ankle dorsiflexion for 6 sec according to verbal command "maximal contraction" and then values of measuring the force were used as analysis values.

For electromyography, we used the MP-150 (Biopac, U.S.A.) system with one recording electrode, TSD150B (Biopac, U.S.A.). Subjects were asked to sit down, straighten their legs, put their ankles in the neutral position and look forward. The hair on the tibialis anterior, to which the electrode was attached, was removed to reduce skin resistance and cleaned with alcohol. The recording electrode was attached below the tibial tuberosity and malleolus. The sampling rate for gathering electromyography signals of the tibialis anterior in ankle joint contraction was 1,000 Hz. Signals were filtered bandpass 20–500 Hz, with a bandstop of 60 Hz. EMGs measured after 5, 10, 15, 20, 25 and 30 repeated contractions were used in the analysis. For each signal, 4 sec, excluding the first and last second was used in the analysis.

The statistical program, SPSS 12.0 program, was used for data analysis and differences in change of measured items between the groups were examined using repeated measured ANOVA. For the comparison of difference between the first contraction and subsequent contractions, Dunnett's t-test was used. For all analyses, a significance level of $\alpha=0.05$ was used.

RESULTS

Repeated measures ANOVA showed there were significant differences in the main effect test ($F=11.36$) for changes in maximal voluntary contraction values of tibialis anterior by group. There were no statistically significant differences between interactions and main effects by time or group. Changes in average maximal voluntary contraction in the electrical stimulation training group showed statistically significant differences after the 15th stimulation compared to the first measurement. Changes in average maximal voluntary contraction in the group combining voluntary motor and electrical stimulation showed statistically significant differences after the 15th stimulation (Table 1).

Repeated measures ANOVA of change in RMS (root mean square) of the tibialis anterior are presented in Table 2. There were significant differences in main effect ($F=11.74$), but there were no statistically significant differences between interaction or main effect by time and group. Changes in average RMS in the electrical stimulation training group showed statistically significant differences only after the 30th stimulation compared to the first measurement time. Changes in amplitude of average effective values in the group combining voluntary motor and electrical stimulation showed statistically significant differences after the 20th stimulation (Table 2).

Repeated measures ANOVA of IEMG of the tibialis anterior showed there were significant differences in change

Table 1. Changes in maximal voluntary isometric contraction (MVIC)

(n=8)	5 th	10 th	15 th	20 th	25 th	30 th
I group (%)	100.0 ± 0.0	96.4 ± 10.4	89.8 ± 16.3*	83.0 ± 17.0*	81.3 ± 14.6*	72.7 ± 18.7*
II group (%)	100.0 ± 0.0	100.1 ± 10.0	101.0 ± 16.5*	95.3 ± 12.3*	96.4 ± 15.8*	89.6 ± 13.1*

Mean ± SD. *p<0.05. I group : Voluntary stimulation training group. II group : Electrical stimulation training group

Table 2. Changes in Root Mean Square (RMS)

(n=8)	5 th	10 th	15 th	20 th	25 th	30 th
I group (%)	100.0 ± 0.0	101.0 ± 18.5	94.5 ± 22.1	88.7 ± 17.7*	92.3 ± 15.8*	88.0 ± 20.5*
II group (%)	100.0 ± 0.0	98.7 ± 12.8	103.0 ± 24.0	97.2 ± 20.4	96.7 ± 20.4	90.7 ± 21.8

Mean ± SD. *p<0.05. I group : Voluntary stimulation training group. II group : Electrical stimulation training group

Table 3. Changes in Integrated electromyograms (IEMG)

(n=8)	5th	10th	15 th	20 th	25 th	30 th
I group (%)	100.0 ± 0.0	96.4 ± 12.6	90.7 ± 17.6	87.4 ± 17.8*	90.0 ± 15.6*	85.5 ± 17.2*
II group (%)	100.0 ± 0.0	99.8 ± 11.1	105.8 ± 23.6	101.8 ± 18.6*	99.6 ± 19.2*	93.7 ± 23.0*

Mean ± SD. *p<0.05. I group : Voluntary stimulation training group. II group : Electrical stimulation training group

Table 4. Changes in Median Frequency (MDF)

(n=8)	5 th	10th	15 th	20 th	25 th	30 th
I group (%)	100.0 ± 0.0	96.3 ± 4.6	93.7 ± 4.0*	91.1 ± 3.3*	90.2 ± 5.5*	91.4 ± 7.8*
II group (%)	100.0 ± 0.0	96.9 ± 3.1	93.8 ± 3.1*	92.3 ± 4.2*	92.8 ± 6.4*	92.2 ± 3.1*

Mean ± SD. *p<0.05. I group : Voluntary stimulation training group. II group : Electrical stimulation training group

in main effect according to time ($F=52.27$). There were no statistically significant differences in interactions and main effects by time or group. Changes in average integral EMG in the electrical stimulation training group showed statistically significant differences after the 20th stimulation. The group combining voluntary motor and electrical stimulation showed statistically significant differences in average integral EMG after the 20th stimulation (Table 3).

Repeated measures ANOVA of the median frequency of the tibialis anterior showed there were no significant differences in changes of the main effect according to time ($F=28.16$). There were no statistically significant differences between interaction by time and group, and main effect by group. Changes in the average median frequency in the electrical stimulation training group showed statistically significant differences after the 15th stimulation. The group combining voluntary motor and electrical stimulation showed statistically significant differences after the 15th stimulation (Table 4).

DISCUSSION

This study was conducted to examine the electrophysiologic responses and changes in the tibialis anterior induced by repeated contraction training. Maximal voluntary isometric contraction in this study significantly decreased with time, and the group combining voluntary motor and electrical stimulation training showed a significant decrease maximal

voluntary isometric contraction after repeated contraction training for a minimum of 15 times. The isometric training group showed greater improvement in than the electrical stimulation group, and it has been reported that voluntary contraction exercise is generally more effective at enhancing muscular strength than electrical stimulation¹¹⁾.

Based on a comparison with previous studies, we consider that significant differences between the electrical stimulation training group and the group combining electrical stimulation and voluntary motor were the result of differences in time and frequency to apply electrical stimulation, regardless of the intensity of training. Since RMS represents the number of motor units during muscular contraction and has a linear relation with EMG activity in isometric contraction, it is often used as an index of muscle strength¹²⁾. RMS in this study significantly decreased with time. The electrical stimulation training group showed a significant decrease in RMS after a minimum of 30 contractions, and the group combining voluntary motor and electrical stimulation training showed a significant decrease in RMS after repeating contraction training a minimum of 20 times. Won¹³⁾ reported that %RMS was reduced by fatigue in isometric exercise. In the present study, the group combining voluntary motor and electrical stimulation training showed results similar to those of preceding studies; However, the electrical stimulation group didn't perform voluntary motor training, and RMS was reduced after a minimum of 30 stimulations.

Integrated EMG of EMG tests is widely used as an index

of muscle strength dividing total signals into section of fixed size and is also the value that area of signal after the process of full wave rectification from raw signal¹⁴). Integrated EMG in this study was significantly decreased with time; and the integrated EMG in the electrical stimulation training group significantly decreased after repeated contraction training for a minimum of 20 times; and in the voluntary motor and electrical stimulation training group, it significantly decreased after repeated contraction training for a minimum of 20 times. Shin et al.¹⁵) reported that as muscular strength of the biceps brachii and rectus femoris muscle continuously increased during a 12-week muscular strength training, integrated EMG rapidly increased within three to six weeks after the start of training. Based on a comparison with these preceding studies, we consider that integrated EMG was reduced due to additional electrical stimulation, even though the same isometric exercise was conducted.

Measurement of local muscle fatigue can evaluate fatigue exactly as a non-invasive method¹⁶). Analysis methods of surface EMG includes median frequency and mean frequency analyses, and the results are used as a fatigue index¹⁷). The median frequency value has reliability and consistency¹⁸). The median frequency increased with time, and the electrical stimulation training group and the group combining electrical stimulation and voluntary motor training showed increases in the median frequency after repeated contraction training for a minimum of 15 times. If voluntary muscle contraction or electrical stimulation of the neurological muscle are continued for a long time, it may cause muscle fatigue. The electrical stimulation group and the group combining voluntary motor and electrical stimulation showed a decline in RMS and median frequency in repeated contraction training of over 15 times¹⁹).

It would be difficult to extend the interpretation of the results of this study to subjects with central nervous system disorders because healthy persons were the subjects of this research. Thus, it was considered that these patients will be available as the basic patients for training of tibialis anterior with normal people or patients.

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