The acute effect of neuromuscular activation in resistance exercise on human skeletal muscle with the interpolated twitch technique

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Abstract. [Purpose] The purpose of this study was to perform a quantitative assessment of neuromechanical adaptation in skeletal muscles and to propose the scientific underpinnings of the acute effects induced by resistance exercise. [Subjects] The subjects in this study were 11 healthy adult men in their 20s who had no orthopedic history at the time of the study. To examine any signs of resistance exercise-induced changes in the ankle plantar flexor, the subjects were directed to perform a standing barbell calf raise routine. [Methods] Subjects were to carry a load equal to their weights and to perform five sets of ten repetitions. The maximal voluntary isometric contraction torque, resting twitch torque, muscle inhibition, root mean square of muscular activation, contraction time, and half relaxation time were analyzed by synchronizing a dynamometer, an electrical stimulator, and an electromyography system. [Results] The maximal voluntary isometric contraction torque appeared to decline, but the change was not statistically significant. The decline of resting twitch torque, on the other hand, was found to be statistically significant. Muscle inhibition and root mean square of muscular activation were both reduced, but both changes were not statistically significant. Lastly, contraction time and half relaxation time both statistically decreased significantly after resistance exercise. [Conclusion] These results indicate that the acute effects of resistance exercise have a greater impact on the peripheral mechanical system itself, rather than on neurological factors, in terms of the generation of muscle force.
Key words: Neuromechanical adaptation, Resistance exercise, Interpolated twitch technique

INTRODUCTION

One of the most important topics in the research on human muscles has been the brain's control over maximal voluntary contractions[1]). This is related to whether the motoneuron pool has sufficient excitability relative to the force the muscle attempts to generate. This can be examined by analyzing the muscular response pattern upon transmission of a maximal electrical stimulus generated by a muscle undergoing a maximal voluntary contraction[2]). A single transmitted electric stimulus is referred to as an "interpolated twitch", and the technique is called "the twitch interpolation technique". As the intensity of a muscular contraction increases, the amplitude of the twitch decreases; the excitability of the motoneuron pool can be measured by assessing the degree of amplitude reduction. One application of this method is measurement of the level of muscular inhibition (MI). Muscular inhibition refers to the amount of muscle inhibited from carrying out a maximal voluntary contraction ordered by the brain. The inhibition occurs via a process in which a supramaximal electric stimulus is transmitted to the nerve connected to the muscle undergoing a maximal voluntary contraction[3]).

In general, resisted movement, a training method to enhance muscular functions, does not increase muscle strength by increasing the number of muscle fibers but rather increases muscle strength by expanding them. Increased muscle strength during the early stages of training is merely the result of the adaptation of neural factors, not the result of muscle hypertrophy[4]). Such neuromuscular adaptation is known to be induced by the use of submaximal stress during the initial stages of training. Similarly, increased muscle strength after long-term resistance exercise is not solely the result of muscle hypertrophy either, as neuromuscular factors may be involved[5, 6]).

Walking and running—the two most representative aerobic exercises—are becoming increasingly popular among people seeking to improve their health. Resistance exercise, a type of anaerobic exercise, is attracting many health-seeking individuals as well. As is evident, many people are engaging in physical activities centered on enhancing cardiopulmonary and muscular functions. Reaping the benefits

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from these exercises requires three or more sessions weekly. Unfortunately, however, many fail to exploit these workouts to their fullest due to an insufficient number of workout sessions, short-term and intermittent workouts, and early termination.

Intermittent participation in exercise may induce delayed muscle pain. Moreover, inappropriate and sudden stress, muscular fatigue, and muscular activation may increase the risk of injury by changing several properties of the muscles[7].

Most of the existing research has simply focused on the changes in outcomes, such as changes in muscular strength or exercise performance after resistance exercise. Any form of change in outcome implies a change in the various internal environments within a muscle; that is, it signifies that there are several neuromechanical changes within the muscle, such as neurological, functional, and mechanical changes, and that the features of these changes are dependent on the exercise load and amount of stimulation. Therefore, it is essential to analyze the internal environment of muscles against a variety of external environmental factors and stimulation conditions in order to determine the causes of change.

Thus, this study employed a neuromechanical approach and used the interpolated twitch technique (ITT) to conduct a comprehensive and multilateral analysis of the neurological, functional, and mechanical changes in human skeletal muscles related to resistance exercise.

SUBJECTS AND METHODS

The subjects in this study consisted of 11 healthy adult males in their 20s, none of whom had any orthopedic history (age, 23.4 ± 1.4 years; height, 178.5 ± 5.2 cm; weight, 75.6 ± 8.7 kg) at the time of the study. The subjects received a complete explanation of the objective and contents of this study, as well as the study procedures, subjects' rights, and safety issues, after which they voluntarily agreed to participate and signed an informed consent in accordance with the ethical standards of the Declaration of Helsinki.

The subjects performed a standing barbell calf raise exercise to examine the changes that occur in the ankle plantar flexors after resistance exercise. To ensure an equal amount of resistance for all of the subjects, the subjects were directed to perform sufficient warm-up activities and to choose a load equal to their weights. They placed the bar on the back of their shoulders with their legs apart at a distance equal to the shoulder length, placed the metatarsal region of their feet on top of a 5-cm block, and raised their heels at a constant speed.

As they raised their heels, the subjects were directed to reach the maximum plantar flexion, utilizing the maximum range of motion (ROM) of their ankle joint, and when lowering their heels, the heels were to be maintained at a point just above the ground. The subjects performed a total of five sets consisting of 10 repetitions per set. All of the subjects took a three-minute break between sets.

The present study measured two types of muscular contractions: a maximal voluntary isometric contraction and a supramaximal muscular contraction after resistance exercise, as generated by a twitch (that the human body cannot produce voluntarily) induced by an artificial electrical stimulation. The equipment used to transmit the electrical stimulus was a Grass 88 SIU-5 electrical stimulator (Grass Technologies, Natus Neurology, Warwick, RI, USA). The pulse duration (0.5 µs) was equally applied to all subjects with an inter-pulse duration of 20 ms.

To determine the optimal stimulation point, the ankle was fixed at 10° in the plantar flexion position, and an anode was attached to the femur above the patella, while a cathode was attached to posterior tibial nerve, which shows the maximum response in the posterior popliteal region. The maximum stimulation point was found by means of singlet stimulation, after which doublet stimulation was applied to induce a supramaximal contraction.

The electrical stimulus was given two times each in consideration of the potentiated effect, and the information about the torques and angles was saved on a personal computer after computing the voltage value from a dynamometer and running it through an analogue-digital (A/D) converter.

A Bagnoli 8-channel wireless electromyography (EMG) system (Delsys, Boston, MA, USA) with a sampling rate of 200 Hz and band-pass filter of 20–45 Hz was used to collect electromyographic signals. The electromyography system was used to measure the level of supramaximal contraction via stimulation of the posterior tibial nerve and the levels of agonist and antagonist activation during a maximal voluntary isometric contraction (MVIC). It was also used to confirm the co-contraction of other muscles.

The electrodes were placed parallel to the muscle fibers located in the center of the muscle belly of the tibialis anterior, soleus, lateral gastrocnemius, and medial gastrocnemius muscles. Before placing the electrodes, the surfaces were shaved and sterilized with alcohol to minimize the skin resistance levels. The electromyographic signals were fed into an A/D converter and later saved on a personal computer.

This study used the LabView 8.0 (National Instruments, Austin, TX, USA) software to collect measurement data and save it onto a personal computer. Torques and angle signals were received from the dynamometer, the signals from the four muscles were received from the electromyography system, and synchronization signals were received from the electrical stimulator. These data were fed into the A/D converter, and the resulting digital data were saved on a personal computer. The voltage value received from the dynamometer was recalibrated and converted to an Nm value for analysis, while the remaining signals were extracted as real data using Chart 5 for Windows (ADInstruments, Colorado Springs, CO, USA) program.

The collected data were statistically analyzed using the SPSS for Windows, Version 12.0, software. The mean (M) and standard deviation (SD) were calculated, and a paired t-test was conducted to compare the difference in each variable before and after the resistance exercise. The level of statistical significance for all analyses was set to α=0.05.

RESULTS

The MVIC torque was found to have decreased from 122.06 ± 21.05 Nm (before exercise) to 116.80 ± 19.71 Nm (after exercise), but the change was not statistically signifi-

cant.

The resting twitch torque also decreased, from 37.04 ± 10.14 Nm (before exercise) to 31.46 ± 8.61 Nm (after exercise), and the change was statistically significant (p<0.01).

MI appeared to have increased from 5.83 ± 6.16% (before exercise) to 7.18 ± 5.05% (after exercise), but the increase was not statistically significant. Moreover, muscle activation slightly decreased from 0.144 ± 0.066 V (before exercise) to 0.139 ± 0.065 V (after exercise), but there was no statistical significance.

The muscle contraction time decreased from 0.13 ± 0.01 msec (before exercise) to 0.12 ± 0.01 msec (after exercise), and the change was statistically significant (p<0.001). Similarly, the half relaxation time was also decreased, from 0.09 ± 0.01 msec (before exercise) to 0.07 ± 0.01 msec (after exercise), and the difference was statistically significant (p<0.001) (Table 1).

DISCUSSION

The present study sought to conduct a comprehensive and multilateral analysis of acute neurological, functional, and mechanical changes in human skeletal muscles after resistance exercise through a neuromechanical approach.

The ITT was developed by Merton in 1954[8] as a means of measuring the inactivation of the adductor pollicis muscle. This technique has been useful in many studies of neuromuscular activation. It has been used in several studies that have reported the level of muscular activation (prominently in the ankle dorsiflexor and plantar flexor[9], the quadriceps femoris muscle[10], and the elbow joint flexor[4]) during a maximal voluntary contraction. Furthermore, the ITT has been used in analyzing the mechanisms of muscular fatigue and muscle weakness induced by a range of causes.

In particular, the ITT has been utilized in studies of neural adaptation during a maximal isometric contraction in relation to physical training[1].

This study used a dynamometer and electrical stimulator to compare and analyze the MVIC torques and twitch torques before and after resistance exercise in an attempt to ascertain the changes in muscular strength induced by resistance exercise. The MVIC was interpreted as a voluntary contraction produced by neural control, and the twitch torque was interpreted as a contraction dependent on the mechanical properties of peripheral nerves without any neural control. The resting twitch torque value was calculated by averaging the two twitches induced by the electrical stimuli, and the resting MVIC torque value was the value at the point of maximum contraction based on the passive torque[11].

The measurements showed that the MVIC torque was lower after resisted exercise, but the change was statistically insignificant. The decrease in resting twitch torque, however, was statistically significant.

These results indicate that there is a greater reduction in muscular strength (after resistance exercise) due to the peripheral mechanical systems of muscles than due to neurological factors[12]. They also signify that although fatigue has an effect on both factors, it has a greater impact on the mechanical factors[13]. Future researchers should conduct further studies on long-lasting fatigue and fatigue reduction

Table 1. Changes in muscle properties of the ankle plantar flexor after heel raise exercise (mean±SD)

Variable	Pre	Post
MVIC (Nm)	122.06 ± 21.05	116.80 ± 19.71
RTT (Nm)	37.04 ± 10.14	31.46 ± 8.61**
MI (%)	5.83 ± 6.16	7.18 ± 5.05
RMS (V)	0.144 ± 0.066	0.139 ± 0.065
CT (msec)	0.13 ± 0.01	0.12 ± 0.01***
HRT (msec)	0.09 ± 0.01	0.07 ± 0.01***

MVIC: maximal voluntary isometric contraction; RTT: resting twitch torque; MI: muscle inhibition; RMS: root mean square of muscle activation; CT: contraction time; HRT: half relaxation time. **p<0.01; ***p<0.001

or recovery factors.

Muscle activation was measured using an electromyography system and the MI value to analyze neuromuscular properties. The MI value was calculated by measuring the twitching plantar flexor torque induced by a supramaximal electrical stimulus applied to the posterior tibial nerve when the plantar flexor muscles were undergoing a maximal voluntary isometric contraction. The root mean square (RMS) of muscular activation was computed by running the measured waveform through the EMGwork 4.1 software (Delsys, Boston, MA, USA). The results indicated no significant changes in the MI or RMS in relation to resisted training.

The statistical insignificance pertaining to muscle inhibition and activation should be examined in association with similar statistically insignificant changes (caused by neurological factors) in muscular strength during an MVIC[14]. Neurological factors not only generate muscle strength but also play a role in the acute effects of resistance exercise. In fact, it can be said that peripheral neurological factors sustain the functional decline of mechanical factors induced by twitching stimulations and that they are less influenced by acute effects overall. The muscle contraction time and half relaxation time were analyzed to examine the functional properties of skeletal muscles. The contraction time refers to the period from rest to the onset of maximum torque, and the half relaxation time refers to the time it takes for the maximum torque value to decline by half. Generally, muscle contraction times and half relaxation times are thought to be prolonged as muscular fatigue accumulates[15].

Likewise, the reductions in contraction time and half relaxation time found in this study appear to stem from muscular fatigue induced by the resistance exercise. Similar to other factors, the measurement variables induced by twitch stimuli all have a statistically significant impact on the acute effects noted during resistance exercise.

In summary, the acute effects of resistance exercise have a temporary impact on the peripheral mechanical system itself, not on the neurological factors, in terms of reducing muscle strength. Future studies should more closely examine the roles of neurological factors in intensifying fatigue and several neuromechanical factors in relation to the periods and lengths of recovery exercises.

ACKNOWLEDGEMENT

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