Effects of Heat Treatment and Rest-inserted Exercise on Muscle Activity

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(Received March 17, 2006. Accepted March 28, 2006)

Abstract

Prolonged immobilization leads to significant weakness and atrophy of the skeletal muscle and can also impair the recovery of muscle strength following injury. Therefore, it is important to minimize the period under immobilization and accelerate the return to normal activity. This study examined the effects of combined heat treatment and rest-inserted exercise on the muscle activity of the lower limb during knee flexion/extension. Twelve healthy subjects were assigned to 4 groups that included: (1) heat treatment + rest-inserted exercise; (2) heat treatment + continuous exercise; (3) no heat treatment + rest-inserted exercise; and (4) no heat treatment + continuous exercise. Heat treatment was applied for 15 mins prior to exercise. Continuous exercise groups performed knee flexion/extension at 0.5 Hz for 300 cycles without rest whereas rest-inserted exercise groups performed the same exercise but with 2 mins rest inserted every 60 cycles of continuous exercise. Changes in the rectus femoris and hamstring muscle activities were assessed at 0 and 2 weeks of treatment by measuring the electromyography signals of isokinetic maximum voluntary contraction. Significant increases in both the rectus femoris and hamstring muscles were observed after only 2 weeks of treatment when both heat treatment and rest-inserted exercise were performed. These results suggest that combination of various treatment techniques, such as heat treatment and rest-inserted exercise, may accelerate the recovery of muscle strength following injury or immobilization.

Key words : electromyography, muscle, heat treatment, rest-inserted exercise

I. INTRODUCTION

Many sports related injuries or spinal cord injury result in either short-term or long-term immobilization of the musculoskeletal system. In addition, the recent increase in life-expectancy leads to more people that may eventually develop diseases of the musculoskeletal system [1-3]. It is necessary for many of these patients to undergo surgery which likely results in significant time under bed rest or disuse of the lower limb. However, it has been shown that inactivity of the lower limb is followed by muscle weakness and significant atrophy of healthy muscle fibers [4-8]. It has been further reported that immobilization significantly impairs the recovery of the strength of the injured skeletal muscle [9-14]. Therefore, prolonged hospitalization and/or recovery periods from these injuries pose a significant social and economical challenge.

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government.

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Injury of the lower limb is detrimental to the quality of life of patients not only during the immobilization period but also after the patient resumes normal activity. Extended periods of disuse has been shown clinically to decrease bone mineral density and muscle mass of the disused limb [15-17]. These factors are likely to result in increased weakness of bone and muscle and consequently increase the susceptibility to subsequent re-injury. Therefore, it is of great importance to design an optimal rehabilitation program and/or system that can minimize the recovery period after the initial injury by maintaining or increasing the mass/activity of the musculoskeletal tissue and in the mean time exercise the non-injured contralateral limb.

Maintenance of muscle mass and structure requires continuous use, similar to other tissues of the musculoskeletal system (e.g., bone, cartilage, tendon, and ligament). It is widely accepted that controlled early resumption of motion can accelerate the recovery of musculoskeletal function and therefore exercise training is extensively used to treat muscle injuries and improve muscle function [18-21]. As a result, commercial continuous passive motion (CPM) devices that allow passive motion to the joint are commonly used to help improve and/or maintain muscle function. It has also been proposed that changes in the loading pattern (e.g., magnitude, frequency, total cycle, etc.)

may significantly influence the musculoskeletal tissue response [22,23]. An interesting loading pattern is the use of rest intervals in between loading cycles where rest-inserted loading has been shown to be more effective compared to continuous loading in musculoskeletal cellular and tissue response [24-28].

Another popular method for stimulation of muscle activity is heat treatment. Most rehabilitation programs related to the musculoskeletal system suggest stretching or warming up of the injured muscle prior to start of the exercise in order to relax the muscles, improve muscle elasticity, and reduce muscle viscosity [29]. For example, heat stimulated muscles displayed higher failure loads, absorbed more energy, and were stiffer than non-heat stimulated muscles [30]. Electromyography (EMG) measurements during constant force sustained isometric contraction are widely used in quantification of muscle strength. For example, maximum voluntary contraction (MVC) is decreased in patients with neuromuscular disorder and training leads to improvement in muscle strength which is accompanied by an increase in EMG activity [31,32].

In this study, we investigated two distinct methods-heat treatment and exercise-used in improving muscle function. Specifically, we examined the effects of combined heat treatment and rest-inserted exercise on the EMG signals of the lower limb muscles.

II. MATERIALS AND METHODS

Twelve people, four male (age = 24.8±3 years, height = 172.4±0.9 cm, weight = 65.9±2 kg) and eight female (age = 20.8±1.5 years, height = 159.5±2.1 cm, weight = 49.9±2.3 kg), with no previous lower limb musculoskeletal disease and no discomfort to flexion and extension of the knee joint, were selected as subjects for the study. They were not performing regular lower extremity resistance trainings the past year as well as during the study period. Subjects were randomly assigned to the following 4 groups where each group consisted of 1 male and 2 female subjects: Group 1) heat treatment + rest-inserted exercise; Group 2) heat treatment + continuous exercise; Group 3) no heat treatment + rest-inserted exercise; and Group 4) no heat treatment + continuous exercise. The left leg of each subject was used for treatment and the contralateral right leg was used as control. The right leg was the dominant leg of all subjects. The study was performed for a total of 2 weeks (5 days/week).

Groups 1 and 2 were subjected to heat treatment immediately before exercise using an electric heating pad. The left thigh muscles were wrapped with the heating pad for 15 mins at 40℃. Care was taken to prevent the contralateral right leg (control) from being exposed to heat treatment. Groups 3 and 4 were not subjected to heat treatment.

Both continuous and rest-inserted exercises were carried out by performing flexion/extension of the left knee with a weight (approximately 4% of subject weight) attached to the ankle of each subject. The contralateral right leg of each subject was not exposed to exercise. Subjects assigned to continuous exercise (i.e., Groups 2 and 4) performed continuous flexion/xtension of the knee at a frequency of 0.5 Hz for a total of 300 cycles with no rest (Fig. 1). One cycle of the knee joint exerse was defined as full extension from the 90° flexed knee joint and then flexed back to the original state (90° flexed knee). Subjects assigned to rest-inserted exercise (Groups 1 and 3) performed flexion/extension of the knee at a frequency of 0.5 Hz for 60 cycles (2 min) followed by 2 min of rest (Fig. 1). Five consecutive sessions of this exercise/rest pattern were performed. The total cycle number of exercise was identical to the continuous exercise groups (300 cycles).

Muscle activities were measured prior to start of the study (Week 0) and at the end of the study (Week 2). EMG signals of isokinetic MVC were measured to analyze the effects of comned heat and exercise treatment by using a muscle testing EMG measurement system (MA100, Motion Lab, U.S.A.). Electrodes were placed over the visual midpoint of the contracted belly of the rectus femoris and hamstring muscles, which are the two dominant muscles in knee flexion/extension motion. Electrodes were also aligned along a line approximately parallel to the

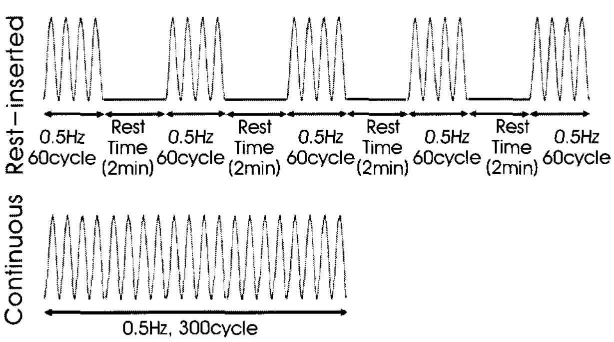

Fig. 1. Waveform of the rest-inserted and continuous exercise. Both exercise groups consist of 300 cycles of flexion/extension motion at a frequency of 0.5 Hz.

direction of the underlying muscle fibers. The muscle testing for isokinetic MVC was performed for 5 s and repeated 3 times for each subject. EMG signals were collected using 1080 Hz sampling rates.

All MVCs were filtered using the butterworth 4th-order bandpass filter with cut-off frequencies at 50 Hz and 500 Hz. The root-mean-squared value of the amplitude of all raw MVCs was calculated over consecutive periods of 100 ms using MATLAB (Mathwork Inc., U.S.A.). Week 2 results were normazed to pre-treatment results (Week 0) to report fold-change. Values are reported as mean ± standard deviation. Paired t-test was used to assess the statistical significance (SPSS Inc., U.S.A.) with a p-value less than 0.05 considered significant.

III. RESULTS

Continuous exercise only (no heat treatment) for 2 weeks had no effect on the EMG signals of both the rectus femoris and hamstring muscles compared to 0 week (Fig. 2 and Fig. 3). Similarly, 2 weeks of rest-inserted exercise only (no heat treatment) did not result in significant changes in the EMG signals of the rectus femoris or hamstring muscle.

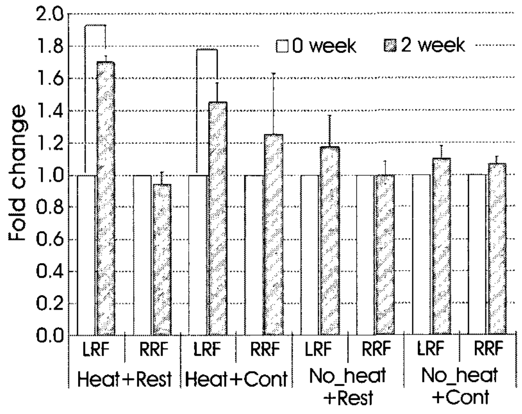

Fig. 2. Muscle activity of the rectus femoris after 0 and 2 weeks of various treatments. Error bars represent standard deviation and brackets significant difference ($p<0.05$). N=3 each.

Application of 15 minutes of heat treatment prior to exercise resulted in significant increases in the EMG signals. When heat treatment was combined with continuous exercise for 2 weeks, there was a 45% increase in the EMG signal of the rectus femoris muscle compared to 0 week ($p=0.003$). However, no significant change was detected in the hamstring muscle. Heat treatment combined with rest-inserted exercise exhibited the greatest effect on the EMG signals. 2 weeks of combined heat and rest-inserted exercise treatment resulted in a 70% increase in the rectus femoris ($p=0.014$) and 28% increase ($p<0.0001$) in the hamstring muscles.

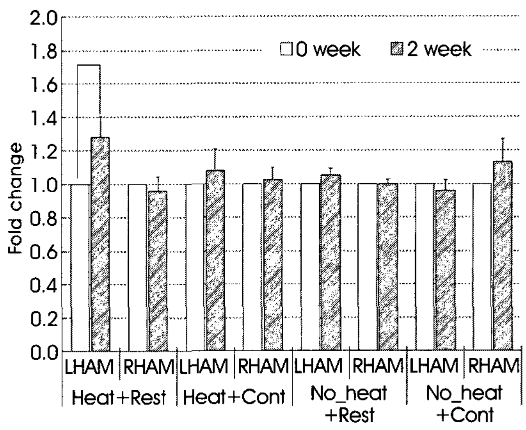

Fig. 3. Muscle activity of the hamstring after 0 and 2 weeks of various treatments. Error bars represent standard deviation and brackets significant difference ($p<0.05$). N=3 each.

Interestingly, greater effects of heat and exercise treatment were observed in the rectus femoris muscle compared to the hamstring muscle. None of the control groups (i.e., muscles of the right limb) displayed significant change in the EMG signals after 2 weeks compared to 0 week confirming that the increase in the EMG signals of muscles of the left limb is due to the 2 week application of heat and exercise treatment.

IV. DISCUSSION

In this study, we examined the effects of two popular methods-heat treatment and exercise-in rehabilitation of muscle function. Insertion of rest in between short bouts of exercise was evaluated compared to continuous exercise. The effect of each type of exercise was studied with or without application of local heat treatment.

Three hundred cycles (i.e., 10 mins) of continuous exercise did not have an effect on the EMG activity of both the rectus femoris and hamstring muscles during MVC even after 2 weeks of treatment. This type of motion which produces simple flexion/extension of the knee joint is similar to the motion used in rehabilitating the knee joint for recovery of muscle strength and range of motion. The motion is also similar to commercial CPM devices which are widely used in rehabilitation of the knee joint [9,11,12]. Consistent with CPM studies that require at least a couple of months of treatment to detect improvement in muscle strength, results from this study also suggest that long-term treatment is necessary to significantly improve muscle activity using simple continuous motion alone.

The same amount of exercise (i.e., 300 cycles) split into short multiple bouts also did not have any effect when applied without heat treatment. Pincivero et al. showed that 160 s of rest inserted in between strength training of 4 week duration resulted in greater improvement in hamstring muscle strength compared to groups that received a shorter 40 s of rest [25] suggesting the importance of rest insertion during exercise. Considering that our study lasted for only 2 weeks, it is possible that further training using this exercise regime will result in significant increases in EMG activity of the thigh muscles.

Heat treatment combined with continuous exercise had no effect on the hamstring muscle EMG signals but resulted in a significant increase in the rectus femoris muscle activity after 2 weeks of treatment. Heat treatment applied in this study is similar to warming up of the muscles prior to exercise which is widely employed in muscle rehabilitation due to its role in reduced susceptibility to injury [33]. Consistent with our results, in vitro studies also show that preconditioning of skeletal muscle cells with heat prior to mechanical stretch can enhance the expression of muscular structural proteins and therefore increase muscular mass and force generation [34].

Increases in both the rectus femoris and hamstring muscle activities were greatest when heat treatment was followed by rest-inserted exercise. Both muscles displayed significant increases in EMG activity after 2 weeks of treatment with the rectus femoris EMG signals increasing by approximately 70% compared to 0 week. This suggests that a more efficient exercise program which consists of heat treatment and rest-inserted exercise may help recover the diminished muscle strength due to immobilization following surgery or disuse.

Interestingly, the rectus femoris muscle appeared to respond better to the training regime employed in this study compared to the hamstring muscle. This may be due to the particular type of exercise performed by the subjects where extension, which primarily uses the rectus femoris, was performed against gravity whereas flexion, which primarily uses the hamstring, was performed with gravity. Therefore, in this study, greater force was necessary to perform extension compared to flexion. Through performance of exercise while adopting different postures it may also be possible to significantly stimulate, for example, the hamstring muscle activity compared to that of the rectus femoris. These observations further confirm the benefit of load-bearing exercise in development of muscle strength.

In this study, the increase in muscle strength was assessed by measuring the EMG signals during isokinetic MVC. Studies show exercise can increase muscle strength initially through neural mechanisms followed by muscle hypertrophy [31,35]. Our findings are consistent with these studies in that a short-term combined heat and rest-inserted exercise treatment regimen significantly increased muscle strength and this increase can be attributed to the recruitment of motor units.

It is well known that exercise by the aged population can maintain/increase muscle mass and strength as well as improve endurance and flexibility. In addition, exercise can accelerate the rehabilitation of muscle strength. This study shows that implement of a well-designed exercise program can further increase the positive effects of exercise even with a shorter training duration. Results from this study also indicate that application of short bouts of continuous passive motion preconditioned with heat treatment has the potential to improve quality of life by maintaining/increasing muscle strength in the aged population and significantly reducing the recovery period and accelerating the return to normal activity by patients undergoing rehabilitation of muscle strength.

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