

Heat Treatment and Rest-Inserted Exercise Enhances EMG Activity of the Lower Limb

Jae Kyun Bang, Sung Jae Hwang, Chang Yong Ko, and Chi Hyun Kim

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 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 + continuous exercise; (3) no heat + rest-inserted exercise; and (4) no heat + 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, 1, 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 2 weeks of treatment only 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 expedite the recovery of muscle strength following immobilization.

Keywords—Electromyography, Heat Treatment, Muscle, Rest-Inserted Exercise.

I. INTRODUCTION

MANY sports related injuries or spinal cord injury result in either short-term or long-term immobilization of the affected musculoskeletal system. In addition, the recent increase in life-expectancy leads to more people that may eventually develop diseases such as arthritis of the knee joint or osteoporosis-related hip fractures [1]-[3]. It is necessary for many of these patients to undergo surgery which may result 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 also been 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.

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 and susceptibility to subsequent re-injury. Therefore, it is of great importance to design a rehabilitation 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 recovery of the musculoskeletal function and therefore exercise training is extensively used to treat muscle injuries and improve muscle function [18]-[21]. It has also been displayed 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 bone cellular and tissue response [24]-[28].

Heat treatment is also used to stimulate muscle activity. 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].

In this study, the optimal method of improving muscle function was investigated. Specifically, we examined the effects of heat treatment and rest-inserted exercise on the electromyography (EMG) signals of the lower limb muscles.

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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 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 + continuous exercise; Group 3) no heat + rest-inserted exercise; and Group 4) no heat + continuous exercise. The left leg of each subject was used for treatment and the contralateral right leg was used as control. The study was performed for 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°C . Care was taken to prevent the 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. Groups assigned to continuous exercise (Groups 2 and 4) performed continuous flexion/extension of the knee at a frequency of 0.5 Hz for a total of 300 cycles (Fig. 1). One cycle of the knee joint exercise was defined as full extension from the 90° flexed knee joint and then flexed back to the beginning state similar to a pendulum motion. Groups assigned to rest-inserted exercise (Groups 1 and 3) performed five sessions of 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). The total cycle number of exercise was identical to the continuous exercise groups.

Muscle activity was measured prior to start of the study (Week 0) and at the end of weeks 1 and 2. EMG signals of isokinetic maximum voluntary contraction (MVC) were measured to analyze the effects of treatment by using a muscle testing EMG measurement system (MA100, Motion Lab, U.S.A.) (Fig. 2). 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 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 through the butterworth 4th-order bandpass filter with cut-off frequencies at 50 Hz and 500 Hz. The root mean square amplitude of all raw MVCs was calculated over consecutive periods of 100 ms using MATLAB

(Mathwork Inc., U.S.A.).

All results were normalized to results from Week 0 to report fold-change. Values are reported as mean $\pm$ standard deviation. Paired t-test was used to assess the statistical significance (SPSS Inc., U.S.A.) with a p-value < 0.05 considered significant.

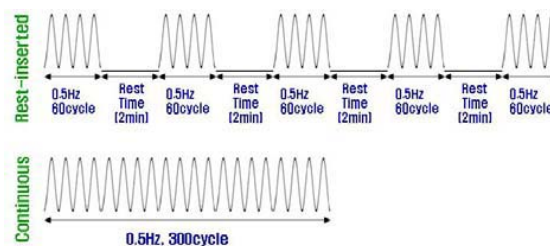


Fig. 1 Waveform of the rest-inserted and continuous exercise. Both exercise groups consist of 300 cycles of flexion/extension motion at a frequency of 0.5 Hz



Fig. 2 Measurement of EMG signals of isokinetic maximum voluntary contraction (MVC) of rectus femoris (left) and hamstring (right) muscles

III. RESULTS

Continuous exercise with no heat treatment for 1 week as well as 2 week had no effect on the EMG signals of both the rectus femoris and hamstring muscles compared to 0 week. Similarly, 1 and 2 weeks of rest-inserted exercise only (no heat treatment) did not result in significant changes in the EMG signals (Fig. 3 and Fig. 4).

Application of heat treatment in addition 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 treatment resulted in a 70% increase in the rectus femoris ($p=0.014$) and 28% increase ($p<0.0001$) in the hamstring muscles.

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 1 and 2 weeks compared to 0 week.

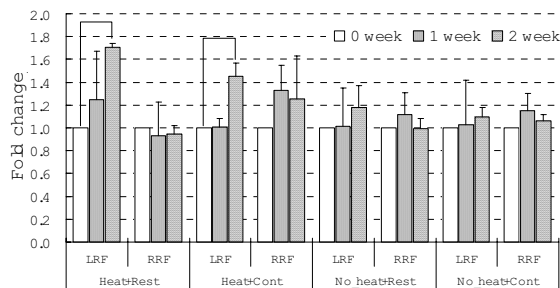


Fig. 3 Muscle activity of the rectus femoris after 0, 1, and 2 weeks of various treatments. Error bars represent standard deviation and brackets significant difference ($p < 0.05$). $N=3$ each

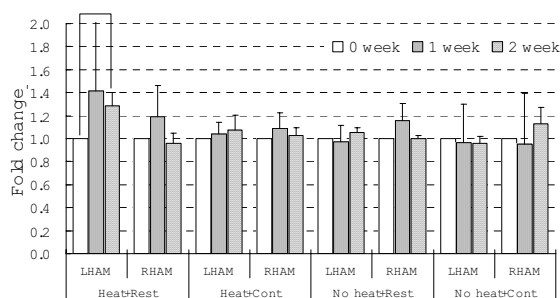


Fig. 4 Muscle activity of the hamstring after 0, 1, and 2 weeks of various treatments. Error bars represent standard deviation and brackets significant difference ($p < 0.05$). $N=3$ each

IV. DISCUSSION

In this study, we examined two distinct methods – heat treatment and exercise - used 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. It is also similar to commercial continuous passive motion (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 improve muscle activity using simple continuous motion alone.

The same amount of exercise 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, further training using this exercise regime may result in significant increases in EMG activity.

Heat treatment combined with continuous exercise had no effect on the hamstring muscle EMG signals but resulted in 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 the reduced susceptibility to injury [31]. 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 [32].

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 training compared to the hamstring muscle. This may be due to the 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. These observations further confirm the benefit of exercise in development of muscle strength.

It is well known that exercise by the aged population can maintain/increase muscle mass and strength as well as improve endurance and flexibility. However, implement of a well-designed program may further increase the positive effects of exercise even with a shorter training duration that can eventually lead to a significantly shorter hospitalization period. Results from this study indicate that application of short bouts of continuous passive motion preconditioned with heat treatment has the potential to improve quality of life by significantly reducing the recovery period and accelerating the return to normal activity.

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