Activity and immobilization after eccentric exercise: I. Recovery of muscle function

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ABSTRACT

SAYERS, S. P., P. M. CLARKSON, and J. LEE. Activity and immobilization after eccentric exercise: I. Recovery of muscle function. Med. Sci. Sports Exerc., Vol. 32, No. 9, pp. 1587–1592, 2000. Purpose: The purpose of the present study was to determine whether activity would affect the recovery of muscle function after high-force eccentric exercise of the elbow flexors. Methods: Twenty-six male volunteers were randomly assigned to one of three groups for a 4-d treatment period: immobilization (N = 9), control (N = 8), and light exercise (N = 9). Relaxed arm angle (RANG), flexed arm angle (FANG), maximal isometric force (MIF), and perceived muscle soreness (SOR) were obtained for 3 consecutive days pre-exercise (baseline), immediately post-exercise, and for 8 consecutive days after the 4-d treatment period (recovery). During the treatment period, the immobilization group had their arm placed in a cast and supported in a sling at 90°. The control group had no restriction of their arm activity. The light exercise group performed a daily exercise regimen of 50 biceps curls with a 5-lb dumbbell. Results: All subjects showed a prolonged decrease in RANG, increase in FANG, loss in MIF, and increase in SOR in the days after eccentric exercise. During recovery, there was no significant interaction observed among groups over time in RANG (P > 0.05) or FANG (P > 0.05), but there was a significant interaction observed among groups over time in both MIF (P < 0.01) and SOR (P < 0.01). Recovery of MIF was facilitated by light exercise and immobilization, whereas recovery from SOR was facilitated by light exercise and delayed by immobilization. Conclusions: The recovery of MIF in both the light exercise and immobilization groups suggests that more than one mechanism may be involved in the recovery of isometric force after eccentric exercise. Key Words: MUSCLE DISUSE, LIGHT EXERCISE, ISOMETRIC FORCE, MUSCLE SORENESS

The question of whether to engage in activity when a muscle has been left sore and damaged after strenuous exercise is one that has not been adequately addressed in the literature. Although many athletes and nonathletes advocate the continuation of activity in the presence of muscular soreness and damage, it is unknown whether this approach will exacerbate injury or enhance the recovery of muscle function.

The loss of muscle function after eccentric exercise is well documented. Changes to the muscle after high-force eccentric exercise include a prolonged loss of muscle force (5,6,11,13,16,23), development of muscle soreness (5–7,11,13,16,17), and a prolonged loss of range of motion (5,6,11,12,17). These changes may last 10 d or more. The prolonged losses in isometric force and range of motion and increases in muscle soreness are associated with muscle damage, and it has been shown that eccentric exercise causes damage to the muscle fiber ultrastructure (6,15).

Few studies have examined the role of activity on recovery of muscle function after eccentric exercise, and the results have been equivocal. Although the following studies did not specifically investigate the role of activity on recovery, some showed that additional eccentric contractions in the days after high-force eccentric exercise had no effect on recovery of muscle function (11,13). Another showed that several bouts of additional concentric contractions in the days after eccentric exercise enhanced recovery of muscle force at higher contraction speeds (31).

In contrast to these studies, a decrease in activity through a short period of immobilization was found to facilitate the recovery of muscle fiber regeneration and tensile strength in the animal model (20) and isometric force recovery in the human model (4). Lehto et al. (20) reported that a 5-d immobilization period in rats followed by remobilization resulted in improved muscle regeneration after injury. In contrast, when immediate mobilization (no immobilization) was implemented after muscle injury, or when only a 2-d immobilization period was implemented followed by remobilization, the result was a decrease in muscle fiber regeneration. In the one human study to specifically examine the recovery of muscle function after eccentric exercise, Clancy and Clarkson (4), in a preliminary investigation, reported that after muscle damaging eccentric exercise, 3 d of immobilization improved the recovery of isometric force but not other indices of muscle function. These two studies suggest that a decrease in activity between 3 and 5 d after strenuous exercise is beneficial to the recovery of muscle function.

The purpose of this study was to determine whether activity would alter recovery of muscle function after...
eccentric exercise. The hypothesis to be tested was that a short period of immobilization after eccentric exercise would result in an improved recovery of muscle function and that augmented activity after eccentric exercise would result in little or no improvement of muscle function in humans.

METHODS

Subjects. Originally, 27 college-age men were recruited to participate in the study, but because one subject exhibited abnormally high responses in several of the indirect indicators of muscle damage, greater than two standard deviations above the mean, we excluded him from the study, resulting in a sample size of 26. After a detailed explanation of the study, subjects signed an informed consent document consistent with the guidelines of the University of Massachusetts Human Subjects Review Committee. Subjects were then randomly assigned to one of three groups: immobilization (N = 9), control (N = 8), or light exercise (N = 9). A sample size of nine subjects per group was estimated using Cohen’s table 2.41 (9) using maximal isometric force as a variable on which to base an effect size. Based on the amount of change in maximal isometric force we would expect to find, an effect size of 4.1 kg (5) and a statistical power (beta) of 0.80 were chosen. All subjects participating in this study were non–weight-trained individuals.

Study design. The 15 consecutive day study consisted of 3 d of baseline measurements, a 4-d treatment period, and 8 d of recovery measurements. A 4-d treatment period was chosen as an intermediate time period between the human (3 d) and animal (5 d) studies, which have shown enhanced recovery of muscle function after damage to the muscle (4,20). During the baseline period, muscle function measurements of relaxed arm angle (RANG), flexed arm angle (FANG), maximal isometric force (MIF), and perceived muscle soreness (SOR) were collected on the nondominant arm. SOR measurements were collected first so that any manipulations of the arm or maximal contractions of the elbow flexors would not influence the perception of soreness. Elbow joint angles were collected next, followed by MIF. This was repeated on each of the baseline days.

When baseline measurements were completed on the third day, the strenuous exercise session of 50 maximal eccentric contractions of the elbow flexors was performed on the nondominant arm of each subject. Immediately after this exercise session, post-exercise muscle function measurements were taken. These consisted of the same muscle function measurements taken during baseline, except for SOR, which does not become elevated immediately after eccentric exercise. It was also on the final baseline day that the Immobilization group had their nondominant arm immobilized in a cast and secured in a sling at 90° immediately after the post-exercise muscle function measurements for the duration of the treatment period. On days 1–4 of the treatment period, the immobilization, control, and light exercise groups visited the laboratory for venipuncture and monitoring of arm activity. Details are provided in part II of this study (29). The light exercise group only was required to perform a daily exercise regimen of 50 biceps curls with a 5-lb dumbbell to provide an increase in the activity of the arm without inducing additional damage to the muscle. Two sets of 25 biceps curls were performed with a 2-min rest between sets. Subjects were instructed to flex and extend the biceps throughout the full range of motion at a slow, steady cadence. Days 5–12 consisted of collecting recovery measurements of RANG, FANG, MIF, and SOR in all groups. This was repeated on each of the 8 d of recovery.

Exercise protocol. The exercise regimen was designed to induce muscle damage through eccentric contractions using a modified preacher curl apparatus. The exercise regimen consisted of 50 maximal eccentric contractions of the elbow flexors of the nondominant arm. While the subject applied maximal resistance against a firm pad located at the distal forearm, the investigator pulled down on a lever causing forced elbow extension. Because of the mechanical advantage offered by the lever system, the investigator was able to exceed the maximal resistance exerted by the subject throughout the entire range of motion. The subject was instructed to maximally resist against the action of the investigator with special emphasis on the end-range of motion, at which subjects typically yield to the external resistance. Each subject performed two sets of 25 maximal contractions, separated by a 5-min rest period. Each action lasted approximately 3 s, with 12 s of rest between actions. The regimen has been previously established to induce a prolonged loss of muscle function (6).

Criterion measures. Elbow joint angles were assessed using a goniometer. The two angles being measured were RANG and FANG. RANG was measured with the arm hanging passively at the side, with the subjects facing straight ahead, with eyes on a fixed point on the wall. FANG was measured with the subjects staring straight ahead, with the elbow fixed at the side as the subject attempted to flex the elbow and touch the shoulder. An indelible marker was used to specify anatomical landmarks to ensure reliability in day to day measures. The mean of the three measurements for each elbow joint angle was used as the criterion measure.

Force was assessed at 90° elbow flexion using a strain gauge attached to a preacher curl machine. The strain gauge was attached to a Jackson force transducer model 32528 (Lafayette Instrument Co., Lafayette, IN). Subjects were seated on a preacher curl machine, with both feet on the floor and the upper arm supported at 45° of shoulder flexion by the padded bench, with the elbow flexed at 90° during the contraction. Three maximal isometric contractions were performed with 45-s rest between trials. Each contraction was held for 3 s, and the mean of the three isometric force measurements was used as the criterion measure.

Soreness was assessed using a 10-point categorical scale with the score of 1 corresponding to no soreness and the score of 10 corresponding to very sore. It has been established in the literature that categorical pain scales are valid and reliable instruments for assessing muscle soreness (25).

To assess their degree of muscle soreness, subjects were instructed to palpate the limb during full range of motion...
biceps curls and then choose the number that corresponded to their perceived level of soreness. One measurement of SOR each session was used as the criterion measure.

**Statistics.** To assess reliability of the baseline measures of RANG, FANG, and MIF, an intraclass R and a repeated measures analysis of variance (RANOVA) was used. To assess changes due to the treatments, a RANOVA was used to determine changes in RANG, FANG, and MIF from pre- to immediately post-eccentric exercise, and also to assess changes in RANG, FANG, MIF, and SOR from the first day post-exercise to the 12th day postexercise. ANCOVA was used assess FANG during recovery, adjusting for differences among groups immediately post-exercise. The level of significance for all tests was set at \( P < 0.05 \). A Tukey’s honestly significant difference (HSD) post hoc test was used to detect differences in MIF and SOR among groups at different time points during recovery and a Bonferroni test adjusted for the number of comparisons. For the analyses of FANG pre- to post-eccentric exercise, the Bonferroni test adjusted the level of significance to \( P = 0.008 \). For the analysis of MIF and SOR during recovery, the Bonferroni test adjusted the level of significance to \( P = 0.002 \).

**RESULTS**

There were no significant differences in age or weight among the three groups; however, the light exercise group was significantly taller (6.6 cm) than the immobilization group (\( P < 0.05 \)). Physical characteristics of the subjects in the study are shown in Table 1. There were no significant differences among the groups or over time in baseline RANG (\( P > 0.05 \)), FANG (\( P > 0.05 \)), or MIF (\( P > 0.05 \)). Intraclass R values for the baseline measures were \( R = 0.97 \) for RANG, \( R = 0.99 \) for FANG, and \( R = 0.97 \) for MIF; thus, the baseline measures proved to be reliable.

When comparing changes from pre- to immediately post-exercise, RANOVA revealed there was a significant main effect for time in RANG (\( P < 0.01 \)), FANG (\( P < 0.01 \)), and MIF (\( P < 0.01 \)) after the eccentric exercise protocol. These post-exercise changes are consistent with responses observed in similar exercise protocols (6). There were no significant group by time interactions in pre- to immediately post-exercise RANG (\( P = 0.70 \)) and MIF (\( P = 0.11 \)). There was a significant group by time interaction in pre- to post-exercise FANG (\( P < 0.05 \)). A Tukey’s HSD test revealed that the immobilization group had a significantly greater mean FANG than the control group immediately post-exercise (\( P < 0.008 \)). The RANG and MIF data suggest that the three groups were similarly stressed during the maximal eccentric contractions; however, the immobilization group may have suffered a slightly greater stress than the control group only, as revealed by the FANG data. The fact that this was found for only one measure may also be due to chance.

All subjects showed a prolonged decrease in RANG, increase in FANG, loss of MIF, and increase in SOR in the days after eccentric exercise. During the 8-d recovery period, there was no significant group by time interaction observed in RANG (\( P = 0.92 \)) or FANG (\( P = 0.26 \)) (see Figs. 1 and 2). Neither activity nor inactivity had any bearing on the recovery of either of the elbow joint angles. However, differences in recovery were found for MIF and SOR, and these differences will be discussed below.

There was a significant group by time interaction observed in MIF (\( P < 0.001 \)) during the 8-d recovery period, suggesting that the pattern of recovery was different among the groups. A Tukey’s HSD test showed that on the first

<table>
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<th>Overall (( N = 26 ))</th>
<th>Immobilization (( N = 9 ))</th>
<th>Control (( N = 8 ))</th>
<th>Light Exercise (( N = 9 ))</th>
</tr>
</thead>
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<td>Age (yr ± SEM)</td>
<td>20.8 ± 0.9</td>
<td>20.3 ± 0.4</td>
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<td>Height (cm ± SEM)</td>
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<td>Weight (kg ± SEM)</td>
<td>77.3 ± 4.9</td>
<td>81.5 ± 7.3</td>
<td>76.1 ± 3.9</td>
<td>76.2 ± 1.8</td>
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**Figure 1**—Relaxed arm angle over 12 d among immobilization, control, and light exercise groups. Note: Pre indicates the baseline period. 0 indicates the time period immediately post-eccentric exercise. Days 1–4 represent the treatment period, and days 5–12 represent the recovery period. Data represent means ± SEM.

**Figure 2**—Flexed arm angle over 12 d among immobilization, control, and light exercise groups. Note: Pre indicates the baseline period. 0 indicates the time period immediately post-eccentric exercise. Days 1–4 represent the treatment period, and days 5–12 represent the recovery period. Data represent means ± SEM.
three days of recovery (days 5, 6, and 7) mean MIF was not significantly different among the three groups \((P > 0.002)\).

On the fourth day of recovery (day 8), the light exercise group had a significantly higher mean MIF than the control group \((P < 0.002)\). On the fifth day of recovery (day 9) until the eighth day of recovery (day 12), both the light exercise group and immobilization group had a significantly higher mean MIF than the control group \((P < 0.002)\). At no point during recovery was the mean MIF of the immobilization group and light exercise group significantly different from each other \((P > 0.002)\).

As shown in Figure 3, the pattern of recovery for both the immobilized group and light exercise group revealed a greater MIF return during the recovery period compared with the control. Immediately after the treatment period on day 5, the control group had recovered the largest percentage of their baseline MIF, 76%, compared with the 71% recovery by the light exercise group and the 68% recovery in the immobilization group. During the next 7 d, however, the control group exhibited a plateau in their recovery, but the immobilization group and light exercise group improved dramatically. MIF recovery from baseline values was not completed by 12 d postexercise in any group, however. The immobilization, light exercise, and control groups recovered 90%, 88%, and 82% of their baseline MIF, respectively.

**DISCUSSION**

By modifying levels of activity after damage to the muscle, it was determined that activity had different influences on the recovery of RANG, FANG, MIF, and SOR. Neither activity nor inactivity had any effect on the recovery of range of motion. Both activity and inactivity resulted in an increase in recovery of MIF. Activity had a positive effect on recovery from SOR, whereas inactivity initially exacerbated the perception of soreness in the muscle.

The most surprising result of the study was that light exercise and immobilization, two treatments at extremes from each other, both resulted in an improved recovery of MIF. The expectation might have been that either one or the other would have resulted in an enhanced recovery of MIF, yet both treatment groups showed improvement after eccentric exercise stress. Because there was no significant difference in the amount of MIF loss immediately after eccentric exercise, the recovery rate should be similar among the groups if there was no treatment effect. It could be suggested that perhaps the control group demonstrated on aberrant, slow recovery of MIF. However, the recovery of baseline MIF observed over 12 d in the control group (82%) was comparable to, and even higher than, what others have found in the literature using similar exercise and testing protocols. Nosaka and Clarkson (24) reported in 16 male subjects that recovery of baseline maximal isometric force 10 d after high-force eccentric exercise was 76%. Chleboun et al. (3) observed that 11 female subjects recovered 78% of their baseline maximal isometric force 11 d after eccentric exercise, although the protocol was not as strenuous as that of the present study. Although we cannot fully rule out the
possibility that the control group may have been more stressed by the eccentric exercise protocol than the immobilization or light exercise groups, the control group demonstrated a typical MIF recovery. Thus, we believe that the improvements observed in MIF recovery in the light exercise and immobilization groups compared with the control group were likely due to the treatment imposed after eccentric exercise and not due to an aberrant force recovery in the control group.

The improved recovery observed in the light exercise and immobilization groups suggests that more than one mechanism was involved in recovery of MIF. Several of the potential mechanisms for the recovery of force observed in both the immobilization group and light exercise group will be discussed next. For the immobilization group, changes in contraction characteristics of the muscle fibers or improved healing in the muscle may have enhanced recovery. Neural factors or the increase in blood flow with exercise may have contributed to enhanced recovery for the light exercise group.

An immobilized muscle exhibits changes in its contractile properties during immobilization (1–3,14). Contraction time shortens and the muscle begins to increase the content of various myosin heavy chain isoforms, toward the characteristics of fast (Type II) muscle fibers. Greater Type II characteristics might lead to an enhanced ability of the muscle to produce force during recovery from immobilization. Changes in contractile properties have been observed during long immobilization periods (3,14). It is unknown whether these changes can occur in the short period of time reflective of our immobilization period (4 d), although 6 d of weaknessness during space flight (another muscle “disuse” condition) has induced rapid changes in contractile properties (28). Thus, an explanation of force recovery based on contractile property changes is speculative at this time.

Another mechanism as to why enhanced recovery of MIF was evident in the immobilization group may be due to improved healing of the muscle fiber itself. In rats, Lehto et al. (20) found that an immobilized muscle fiber increased its ability to withstand rupture when remobilization occurred after a short immobilization period. Disruption of this process by early remobilization was shown to delay muscle fiber regeneration. However, this mechanism does not explain why the light exercise group, experiencing a potentially greater disruption of their muscle fibers during their remobilization, showed an increased recovery of MIF.

Neural factors might contribute to force recovery when light exercise is performed after eccentric exercise. It has been established that as ultrastructural damage to the muscle fiber worsens in the days after eccentric exercise, maximal isometric force of the muscle is returning (6,15). If muscle fiber damage is worsening as maximal isometric force recovers, there may be some neurally mediated adaptation in response to exercise facilitating isometric force recovery. Altered EMG patterns are reported to occur up to 48 h after eccentric exercise (18). An adaptation may occur in motor unit recruitment patterns, possibly bypassing the more damaged muscle fibers, leading to an enhanced recovery of force.

An increase in blood flow could be a mechanism responsible for the enhanced recovery of muscle force when light exercise is performed during recovery. Research using concentric contractions showed that blood flow increased up to five-fold immediately upon the release of muscle contraction (27). Blood flow has been established as an important factor in reducing pain, improving the healing of damaged muscle, reducing swelling, and improving circulation (22) as well as improving the efficiency of muscle contraction (8). Although blood flow to the muscle may enhance the recovery of MIF in the light exercise group, this does not address the improvement in the recovery of MIF observed in the immobilization group. Recent studies have reported decreased blood flow during hindlimb unweighting (21) and a decreased capillary to fiber ratio with immobilization (2,10,19,26), which reduces blood supply to the muscle. Because there is a paucity of research examining blood flow during short periods of immobilization such as those used in the present study, it is unknown what effect 4 d of immobilization had on blood flow, but it is likely reduced.

SOR appeared to be exacerbated by immobilization after high-force eccentric exercise. SOR was significantly greater in the immobilization group than in either the control or light exercise group on the last day of the treatment period and during the first day of the recovery period. This could be due to a delay in the removal of pain-generating inflammatory products after eccentric exercise. After high-force eccentric exercise, the inflammatory response results in the accumulation of neutrophils and macrophages at the site of tissue injury (6,30). Macrophages synthesize an abundance of prostaglandins (PGE$_2$) which sensitizes the Type III and Type IV pain afferents, resulting in muscle soreness. These substances may accumulate in the muscle during immobilization due to a reduction in blood supply to the muscle. It is possible that impaired circulation could result in a trapping of noxious stimuli in the muscle, leading to an enhanced sensation of muscle soreness. There was a precipitous drop in SOR in the immobilized group after remobilization of the muscle. The fact that there was no difference in SOR among the three groups on the second day of recovery (day 6) lends support to the possibility that increased activity may help to reduce SOR during the early stages of recovery.

It is interesting to note that light exercise had no effect on RANG or FANG. Perhaps this is further evidence for altered neural patterns after eccentric exercise. If light exercise facilitated a neural adaptation, then MIF and SOR (which is activated upon movement) would be positively affected, whereas passive measures such as RANG and FANG would not. However, a neural adaptation does not adequately address why immobilization had no effect on these range of motion measurements.

The fact that both immobilization and light exercise resulted in an improved recovery of muscle function after high-force eccentric exercise was unexpected. This finding suggests that more than one mechanism of isometric force recovery may be operating in the muscle after muscle injury. Because light exercise resulted in a reduction in SOR and an
enhanced recovery of MIF after eccentric exercise, for some individuals the addition of light exercise during the recovery period from strenuous, overexertion exercise may be beneficial. Future studies should attempt to elucidate the mechanisms of maximal isometric force recovery after exercise damage and further evaluate the benefits of immobilization and light exercise during recovery.

REFERENCES