Original Article

Effects of Immobilization and Active Mobilization on Recovery of Muscle after Eccentric Exercise

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This study compared the effects of immobilization (IM) and active mobilization (AM) on recovery from eccentric exercise. Thirty-three college-age males were randomly placed into one of the three groups: IM (n = 11), AM (n = 11), and control (CON; n = 11). All subjects performed a bout of 50 maximal eccentric actions of the elbow flexors (ECC) using a dumbbell set at 100% of the pre-exercise maximal isometric force (MIF). Thirty minutes after ECC, subjects in the IM group had their elbow joint immobilized by a cast and secured in a sling at a joint angle of 90° for four days. Subjects in the AM group performed 50 biceps curl actions with a dumbbell (5 lb), 30 minutes post-ECC and one to four days after ECC. There was no treatment in the CON group. MIF, active range of motion (ROM), upper arm circumference (CIR), and muscle soreness were measured before, immediately after, and four to 10 days following ECC. Plasma creatine kinase (CK) activity was assessed before and for 10 days after ECC. All measures changed significantly ($p < 0.05$) after ECC for all groups, without significant differences immediately post-ECC. Recovery of MIF was faster for the AM and IM groups compared to CON ($p < 0.05$), whereas no differences among the groups were evident for muscle soreness and ROM. Both IM and AM groups showed smaller increases in CK compared to CON, and increases in CIR were also reduced for IM ($p < 0.05$). These results suggest that both IM and AM enhanced the recovery of MIF, and had an effect on CK.

Keywords: strength, plasma creatine kinase activity, muscle soreness, swelling, range of motion

Introduction

It is well documented that eccentric exercise induces muscle damage, which is characterized by prolonged loss of strength and range of motion (ROM), development of muscle soreness, elevated muscle proteins in the circulation such as creatine kinase (CK) activity and limb swelling (Connolly et al. 2003; Clarkson & Hubal 2002; Clarkson et al. 1992). These changes may last 10 days or more after a single bout of intensive eccentric exercise (Connolly et al. 2003; Clarkson & Hubal 2002). The underlying mechanisms of exercise-induced muscle damage (EIMD) have yet to be understood, but it has been documented that EIMD is initiated by mechanical strain to disrupt internal membrane system and sarcomeres (Proske & Morgan 2001; Warren et al. 1999).

Although many prophylactic or therapeutic modalities are used for the treatment of EIMD, most of the treatments have yet to be confirmed for their efficacy. Reduced activity has been reported to facilitate the recov-

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ery of muscle strength (Kraemer et al. 2001; Sayers et al. 2000a). Sayers et al. (2000a) showed that four days of immobilization enhanced strength recovery and delayed development of soreness. Five days of compression was also reported to be effective in preventing decreases in ROM, decreasing soreness and swelling, and promoting recovery of strength (Kraemer et al. 2001). These studies suggest that reduced activity is beneficial for the recovery of muscle function in EIMD.

On the other hand, Sorichter et al. (1995) showed that several bouts of concentric exercise in the days following eccentric exercise facilitated recovery of strength. Sayers et al. (2000a) recently reported that recovery of strength and soreness was enhanced when light exercise was performed one to four days after eccentric exercise. It appears that active mobilization is also effective for the recovery of muscle function in EIMD. However, other studies failed to find such effects of light exercise (Gulick et al. 1996; Saxton & Donnelly 1995; Weber et al. 1994; Donnelly et al. 1992). Thus, the role of active mobilization on recovery of muscle function following eccentric exercise remains uncertain (Connolly et al. 2003).

Controversy exists concerning whether muscles suffering from EIMD should be rested or moved. Sayers et al. (2000a, 2000b) compared immobilization and active mobilization for its effect on development of muscle soreness (DOM), muscle function, and other symptoms of muscle damage. They showed that both treatments enhanced recovery of strength, but only active mobilization facilitated the recovery of soreness. It should be noted that the opposite treatments of immobilization and mobilization produced a similar effect on muscle strength, but this needs to be confirmed. Therefore, the purpose of the present study was to examine whether immobilization and active mobilization of the muscles that performed eccentric exercise would affect the recovery of muscle function and symptoms associated with EIMD.

Methods

Subjects

Thirty-three male students participated in this study, and their mean (± SD) age, height, and weight were 21.2 ± 3.1 yrs, 173.4 ± 4.0 cm, and 67.7 ± 5.6 kg, respectively. All subjects provided their informed consent documents, which were reviewed and approved by the local Human Subjects Review Committee. All subjects were well-trained soccer players who had been playing soccer for six to 10 years and trained at least five days a week (> 14 hours). In their regular training schedule, they reported the performance of resistance training two to three times per week, for pre-season, and once a week for in-season in the past year. This study was conducted during their off-season, and subjects were asked not to perform any unaccustomed exercise or vigorous physical activities during the experimental period. Based on the maximal isometric force (MIF) measured at two days prior to eccentric exercise and immediately before eccentric exercise, the subjects were placed into one of three groups: active mobilization (AM; $n = 11$), immobilization (IM; $n = 11$) and control (CON; $n = 11$) groups.

Study design and procedure

The experimental period consisted of 13 days: two days of baseline measurements, four days of treatment, followed by seven days of recovery. All subjects performed 50 maximal eccentric contractions of the elbow flexors (ECC) of the non-dominant arm on the third day. In the exercise, subjects lowered a dumbbell from an elbow flexed (elbow joint angle was approximately 50°) to an elbow extended position (elbow joint angle was approximately 180°). This action was performed over approximately three seconds on an arm curl bench (Clarkson & Tremblay 1988). Using a timer, the investigator guided the velocity of eccentric action, and asked that subjects maintain velocity as well as they could. The investigator brought the dumbbell up to the elbow-flexed position after each eccentric contraction. After each eccentric action, 45 seconds of rest was given. The weight of the dumbbell was set at 100% of pre-exercise MIF. MIF was measured by taking the average of six, three-second contractions from one day before and immediately prior to ECC with the elbow angle set at 90°.

After taking measurements immediately after exercise (about 30 minutes post exercise), the IM group had their arm immobilized in a cast and secured in a sling at 90° for the next four consecutive days. The AM group, on their part, performed a bout of 50 biceps curls (2 sets of 25 reps with 2 minutes rest between sets) with a 5-lb

dumbbell, 30 minutes, and one, two, three and four days after ECC. The load was chosen based on previous studies (Sayers et al. 2000a, 2000b), and subjects were instructed to flex the elbow joint slowly from an elbow extended (180°) to a flexed (50°) position in five seconds. At the flexed position, the dumbbell was removed and the arm was brought back to the extended position without load and given a five-second rest. Therefore, the total exercise time was 8.3 minutes with an actual muscle contraction time of 250 seconds.

Criterion measures

Criterion measures included MIF, active ROM, upper arm circumfrence (CIR), muscle soreness and plasma CK activity. MIF, ROM, CIR, and muscle soreness were measured before ECC, immediately after ECC and at 24-hour intervals for seven consecutive days after the four initial treatment period days (i.e. from day 4 to day 10, after ECC). Immediately prior to ECC, and at one through 10 days after ECC, all subjects visited the laboratory for morning blood sampling. From these samples, plasma CK activity was assessed.

MIF was recorded for three seconds at the elbow angle of 90°, on a modified arm curl machine using a force transducer (Model UG, Biopac Systems, Inc., Santa Barbara, CA, USA) connected to a digital recorder (TSD150, Piopac Systems, Inc., Santa Barbara, CA, USA). Three trials were performed with a one-minute rest between each contraction.

Flexed (FANG) and relaxed (RANG) elbow joint angles were measured three times for each time point using a goniometer (Creative Health Products, Plymouth, MI, USA). FANG was assessed when the subjects tried to fully flex the elbow to touch the shoulder by the palm, while keeping the elbow at the side. RANG was the angle where the subjects relaxed the arm, allowing it to hang down by the side. A semipermanent marker was used to identify the landmarks such as the lateral center point of the humerus (near to shoulder joint or between greater tubercle and lesser tubercle), the lateral center point of elbow joint, and the lateral center point between radius and ulna (near the wrist joint) for the goniometer placements. ROM was calculated by subtracting FANG from RANG (Chen 2003; Nosaka & Clarkson 1996).

CIR was measured at eight cm above the elbow joint with a Gulick tape measure, while allowing the arm to hang down by the side (Chen 2003; Nosaka & Clarkson 1995). This point was marked on the participant's arm to ensure consistent placement of the tape measure.

The muscle soreness data were analyzed using a visual analog scale of a 100-mm continuous line that represents "not sore at all" at one side (0 mm) and "very, very sore" at the other side (100 mm). Subjects were asked to report the soreness level on the line when an investigator palpated over the biceps brachii and extended the elbow (Chen 2003, Nosaka & Clarkson 1996).

Blood analysis

A 10mL venous blood sample was collected using standard venipuncture technique from the cubital fossa region of the dominant arm by a qualified nurse. Each vacutainer containing EDTA was centrifuged for 10 minutes to obtain plasma, and plasma CK activity was assessed spectrophotometrically using a Genstar chemistry analyzer (Electro-Nucleonics, Inc., Fairfield, NJ) and a commercially available diagnostics kit (Procedure No. DG147–UV, Sigma Diagnostics, St. Louis, MO) within six hours (Chen 2003). Samples were analyzed in duplicate, and the mean value was used for subsequent statistical analysis.

Statistics

Changes in the criterion measures over time were analyzed using two-way repeated measures ANOVA. A Tukey's *post hoc* test was used to assess differences between the groups during and/or after the treatment period. The level of significance for all tests was set at $p < 0.05$.

Results

The amount of work performed during ECC was similar among groups. MIF dropped approximately 50% ($p < 0.05$) of the pre-ECC value immediately after ECC for all groups (Figure 1). Therefore, it seems likely that the initial effect of ECC on the elbow flexors was not different between groups.

All subjects demonstrated a prolonged loss in MIF and ROM, increases in CIR and muscle soreness, and increases in plasma CK activity in the days following ECC (Figures 1 to 5). MIF and ROM decreased significantly

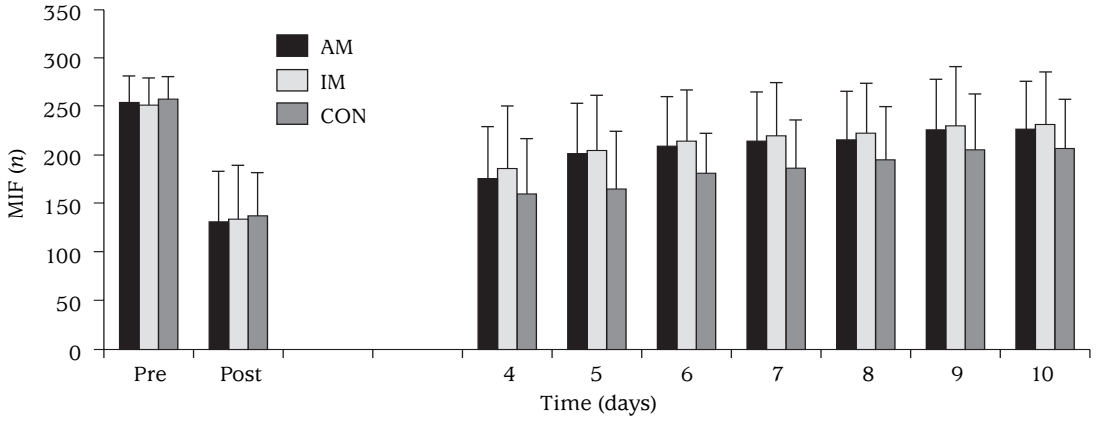

Fig. 1 Changes in maximal isometric force (MIF) over 10 days after eccentric exercise for the immobilization (IM), active mobilization (AM) and control (CON) groups. Note: "Pre" indicates the baseline period; "Post" indicates the time period immediately post-ECC (maximal eccentric contractions of the elbow flexors); days one to four represent the treatment period, and days four to 10 represent the recovery period; MIF measurements were taken on the last day of the treatment period (day 4) as well as during the seven days of recovery.

* There were significant differences ($p < 0.05$) between groups on day 5 to 10 after ECC. Values shown are means ± standard deviations.

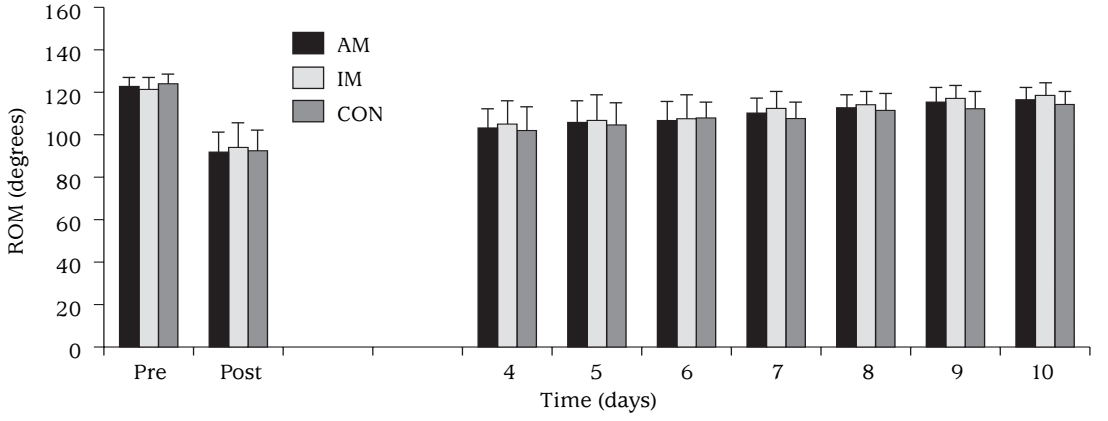

Fig. 2 Changes in active range of motion (ROM) over 10 days after eccentric exercise for the immobilization (IM), active mobilization (AM), and control (CON) groups. Note: "Pre" indicates the baseline period; "Post" indicates the time period immediately post-ECC (maximal eccentric contractions of the elbow flexors); days one to four represent the treatment period, and days four to 10 represent the recovery period; ROM measurements were taken on the last day of the treatment period (day 4) as well as during the seven days of recovery; there were no statistically significant differences ($p > 0.05$) between groups. Values shown are means ± standard deviations.

($p < 0.01$) immediately after ECC, recovered gradually thereafter, but did not return to the pre-ECC levels by 10 days after ECC (Figures 1 and 2). Soreness peaked at four days after ECC and returned to pre-ECC value by seven days after ECC (Figure 3). CIR peaked around six days after ECC and returned to pre-ECC value by 10 days after ECC (Figure 4). Plasma CK activity peaked five days after ECC and did not completely return to the pre-ECC level by 10 days after ECC (Figure 5).

During the later recovery days (7 to 10), significant differences ($p < 0.05$) in MIF (Figure 1) and CIR (Figure 4) were evident between the treatment (AM, IM) and CON groups. However, no differences between groups were found for ROM (Figure 2) and muscle soreness (Figure 3). Immediately after the treatment period (4 days after ECC), the level of MIF for the AM, IM, and CON groups were 68%, 74%, and 62%, respectively, with a significant difference ($p < 0.05$) between IM and CON. Be-

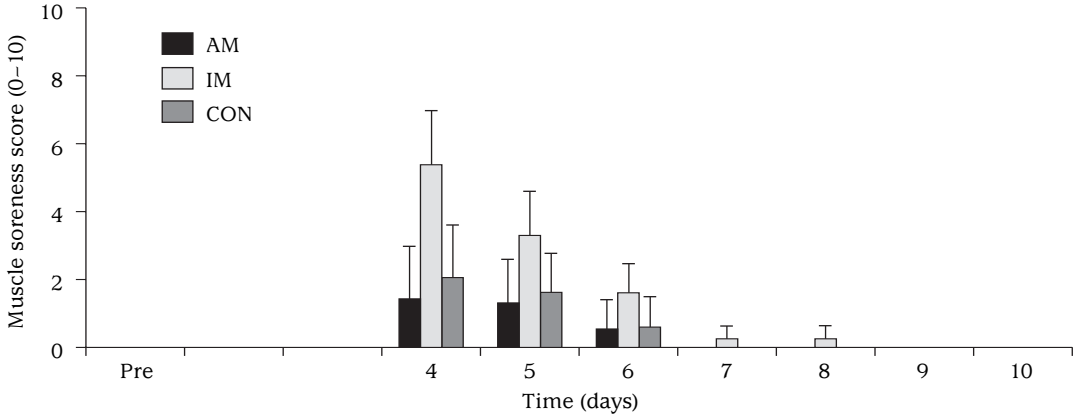

Fig. 3 Changes in muscle soreness score over 10 days after eccentric exercise for the immobilization (IM), active mobilization (AM), and control (CON) groups. Note: "Pre" indicates the baseline period. Days one to four represent the treatment period, and days four to 10 represent the recovery period; soreness measurements were taken on the last day of the treatment period (day 4), as well as during the seven days of recovery; there were no statistically significant differences ($p > 0.05$) between groups. Values shown are means ± standard deviations.

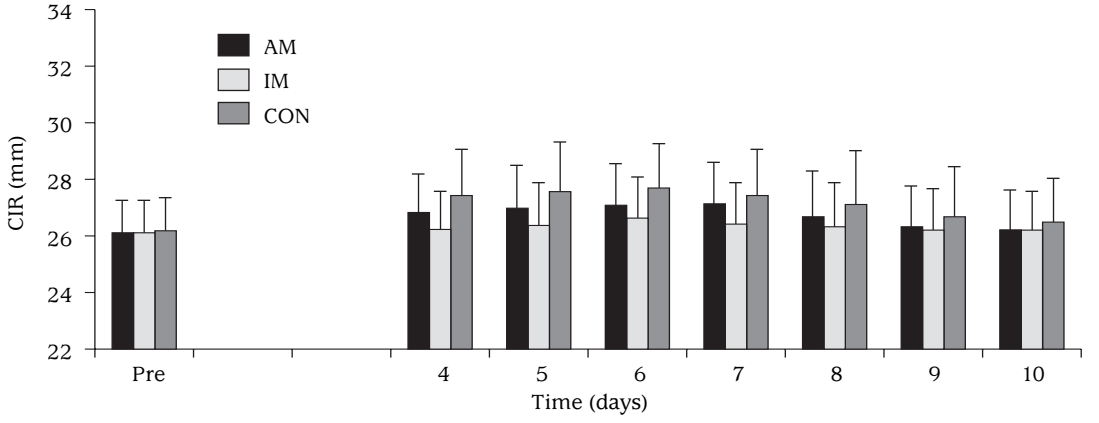

Fig. 4 Changes in upper arm circumference (CIR) over 10 days after eccentric exercise for the immobilization (IM), active mobilization (AM), and control (CON) groups. Note: "Pre" indicates the baseline period; days one to four represent the treatment period, and days four to 10 represent the recovery period; CIR measurements were taken on the last day of the treatment period (day 4), as well as during the seven days of recovery.

* There were significant differences ($p < 0.05$) between groups on day 4 to 8 after ECC. Values shown are means ± standard deviations.

tween four and 10 days after exercise, the recovery of MIF was significantly smaller for the CON group (80% at day 10), compared to the AM (90%) and IM (93%) groups. The IM group showed significantly smaller increases in CIR four to eight days after ECC, compared to the CON group.

Figure 5 shows changes in plasma CK activity following ECC. All groups showed a significant increase ($p < 0.05$) in plasma CK activity, but the magnitude of increase was significantly lower for the IM and AM groups, compared to the CON group, during and after treatment periods. Plasma CK activity peaked five days after ECC for all groups with 3,837 IU/L, 763 IU/L, and 6,161 IU/L for the AM, IM, and CON groups, respectively. The peak value was significantly ($p < 0.05$) different between AM and CON, IM and CON, and AM and IM, respectively.

Discussion

The results of the present study showed that recovery of MIF after ECC was faster in the AM and IM groups by

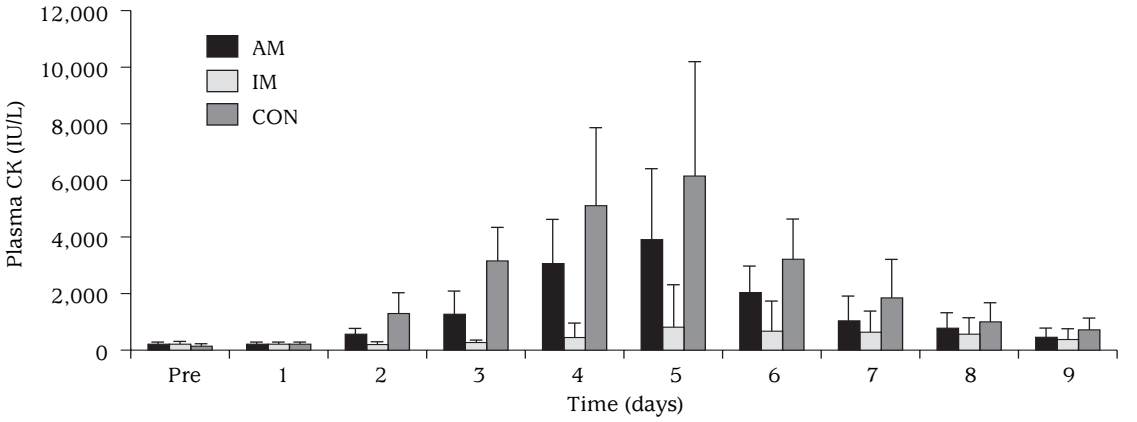

Fig. 5 Changes in plasma creatine kinase (CK) activity over 10 days after eccentric exercise for the immobilization (IM), active mobilization (AM), and control (CON) groups. Note: "Pre" indicates the baseline period; days one to four represent the treatment period, and days four to 10 represent the recovery period; plasma CK activity levels were assessed before, and at 24-hour intervals, for 10 days after ECC.

* There were significant differences ($p < 0.05$) between groups on day 2 to 7 after ECC. Values shown are means ± standard deviations.

comparing with that of the CON group (Figure 1). These results supported previous studies that reported that limiting the use of the damaged muscles (Kraemer et al. 2001; Sayers et al. 2000a), or using the damaged muscles actively (Sayers et al. 2000a; Sorichter et al. 1995), facilitated the recovery of muscle strength after eccentric exercise.

It is interesting that the opposite treatments had the same effect on recovery of muscle strength (Figure 1). However, it should be noted that the duration of the treatment time was not the same. The elbow flexors were immobilized continuously for four days, but actively moved intermittently by the concentric exercise during the same recovery period (actual exercise time was approximately 4 minutes). Compared to the control condition, it seems reasonable to assume that muscle activity was reduced in the immobilization treatment, but how much increase in muscle activity was added to the control condition is not clear, as no muscle activity measurements were taken in this study. Sayers et al. (2000a) reported that both four days of immobilization and light exercise performed similarly to the present study enhanced strength recovery. They also stated that more than one mechanism was involved in recovery of muscle strength (Sayers et al. 2000a). The results of the present study confirmed the findings of the study by Sayers et al. (2000a).

This study also found that soreness and ROM were not affected by either treatments (Figures 2 and 3), and increases in CIR were attenuated in the immobilization group (Figure 4). These results are different from those by Sayers et al. (2000a) and Kraemer et al. (2001). Sayers et al. (2000a) showed that immobilization exacerbated muscle soreness but had no effect on ROM. Kraemer et al. (2001) reported that a five-day period of continuous compression decreased the extent of soreness and swelling, but had no effect on ROM. It might be that the reduction in movement allowed for quicker healing by attenuating the inflammatory response following EIMD (Clarkson & Sayers 1999; Arnheim 1985). It is possible to speculate that immobilization enhanced healing in the muscle. Lehto et al. (1985) reported that five days of immobilization after injury increased the ability to cover the injury area and to have sufficient tensile strength to withstand mobilization (rupture), allowing newly-formed granulation tissue to cover the injured area. Immobilizing injured soft tissue for two to three days is a common practice to help ensure healing of the wound without complication (Arnheim 1985). Placing external pressure on the damaged muscles assists decreasing further the secondary damage (inflammatory response) (Kraemer et al. 2001; Arnheim 1985). Immobilization may serve as an external mechanical support to the muscle, thus facilitating a rapid recovery of muscle strength (Kraemer et al. 2001; Arnheim 1985).

Another possible explanation for the enhanced recovery of strength in the IM group is through changes

in muscle contractile ability through immobilization. It has been reported that a six- to seven-day period of disuse (space flight) increased Type IIx myosin heavy chain isoforms in animals (Caiozzo et al. 1994). Koryak (1998) reported a small increase in maximal rates of force development of the human triceps surae muscle after seven days of simulated space flight by "dry" water immersion, and suggested that myosin ATPase activity and maximal velocity by shortening were enhanced. The shift to the fast twitch characteristics might lead to an ability to produce higher muscle force (Sayers et al. 2000a). However, it is not known whether the four days of immobilization in this study produced the shift of muscle fiber type.

Active mobilization has also been reported to enhance the recovery of muscle strength. It would appear that in this study, increases in blood flow by light exercise played a role in the recovery of muscle strength (Sayers et al. 2000a). Previous studies showed that muscle blood flow increased up to five-fold during concentric exercise (Robergs et al. 1997). Blood flow is an important factor in reducing pain, facilitating the healing of damaged muscle, and reducing swelling (Mohr et al. 1987), as well as enhancing the efficiency of muscle contraction (Clemente et al. 1991). This would explain the enhanced recovery of strength shown for the AM group in the present study (Figure 1), although soreness and swelling was not affected by exercise (Figures 3 and 4).

Increased CK activity in the blood is often used as a biochemical marker for skeletal muscle damage after eccentric exercise (Nosaka & Clarkson 1996; Clarkson et al. 1992). After intense eccentric exercise, a significant elevation in CK activity does not occur until two days after exercise, and reaches a peak after three to six days (Clarkson & Hubal 2002; Nosaka & Clarkson 1996; Clarkson et al. 1992; Clarkson & Tremblay 1988). We found that the IM and AM groups showed significantly lower increases in plasma CK activity than the CON group during and after treatment periods following ECC (Figure 5). The blunted CK response is similar to previous studies showing that inactivity and light exercise following ECC produces lower CK responses (Kraemer et al. 2001; Sayers et al. 2000b; Havas et al. 1997). It has been documented that reduced activity may decrease CK release from the muscle or lymphatic transport (Sayers et al. 2000b; Havas et al. 1997).

Sayers et al. (2000b) postulated that immobilization decreases the movement of enzymes such as CK from the interstitium into the circulation through the lymphatic system, and may result in diminished CK level in the circulation. Thus, our data lend some support to the possibility that the lower increases in plasma CK activity in the immobilization condition is due to a reduction in lymphatic transport. On the other hand, the increased plasma CK activity in the AM group may be due to increases in lymphatic flow. In animal models, Lindena et al. (1979) showed that increasing the muscular activity of dogs resulted in an increase in the lymphatic transport of CK and other enzymes compared to resting dogs. In human models, Sayers et al. (2000b) and Sorichter et al. (1995) showed that active movement of the muscles after ECC enhanced release of CK into the blood. Therefore, the results of this study support the possibility that plasma CK activity is influenced by lymph flow.

In conclusion, the results of our study showed that both immobilization and active mobilization of the muscles that performed maximal eccentric exercise had a positive effect on the recovery of muscle strength. The immobilization treatment also reduced swelling and responses of plasma CK activity. It should be noted that the opposite treatments produced a similar effect on the recovery of muscle strength. It would appear that either complete rest or active utilization of the sore muscles can facilitate the recovery process. However, how immobilization and exercise produced the similar effect warrants further examination.

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