Original Articles

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Effect of Local Cooling and Blood Flow Restriction on Muscle Weakness and Atrophy Caused by Detraining

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Objective: To prevent muscle weakness and atrophy that are caused by discontinuing sports activities, we investigated the effect of local cooling and blood flow restriction (BFR) during detraining.

Methods: Eleven healthy men (23.8 ± 2.1 years) performed elbow flexion resistance training three times per week for 6 weeks. After training, the subjects were instructed to limit the upper arm activity within their activities of daily living level during 3 weeks of detraining. During the detraining period, one arm was used as a control (CON, n = 11); the other arm was used under the condition of cooling at medial side of upper arm by an ice bag (ICE, n = 6), or under BFR (BFR, n = 5). Measurements included elbow flexion torque at angular speeds of 60°/s and 120°/s under concentric contraction and isometric contraction (IM) and cross-sectional area of the upper arm.

Measurements were conducted at pre-training (Pre); post-training (Post); and after 1week (W1), 2 weeks (W2) and 3 weeks (W3) of detraining.

Results: IM torque and cross-sectional area significantly increased following training in all conditions. During detraining, IM torque significantly decreased under the CON condition (Post, 73.2 ± 19.9 Nm; W3, 64.3 ± 11.6 Nm), but no significant changes were observed under ICE condition. However, BFR condition significantly increased following detraining. The percent change in each condition during detraining was significant between the CON and BFR conditions at W2 and W3. Cross-sectional area significantly decreased following detraining in all conditions.

Conclusions: Local cooling and BFR suppressed muscle weakness that was caused by detraining.

Key words: cessation of training, ice cooling, blood flow restriction, muscle strength, muscle cross-sectional area

Introduction

Detraining means temporarily or permanently cessation of training because of various reasons, such as injury. Detraining has been reported to reduce activity levels and cause a decrease in muscle strength and mass. Hortobágyi *et al.*[1] reported that 2 weeks of detraining in sports players led to a 12% decrease in muscle strength and 6% decrease in muscle cross-sectional area. Moreover, Jespersen *et al.*[2] reported an 11% incidence of muscle atrophy within 10 days of detraining after 90 days of training, suggesting that even short-term cessation of training may cause muscle atrophy. Terzis *et al.*[3] reported that muscle strength and throwing performance after 14 weeks of full-body training significantly decreased after 4 weeks of detraining. Therefore, decreased muscle strength is associated with loss of performance. Suppressed muscle weakness and atrophy caused by detraining is an important issue for early return to sports activities.

In sports, cooling is used as a first-aid treatment to suppress inflammation and pain on injury. With cooling, ice is locally applied to the site of injury, usually for 20–30 min. Cooling is a simple treatment

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that can be performed and continued even after an injury. Recently, it has been reported that a combination of training and cooling increased muscle strength enhancement[4] and that continuous daily exposure to a cold environment for a short period inhibited muscle atrophy in microgravity[5]. Moreover, another study found that exposure to a cold environment activated the proteins involved in muscle atrophy[6]. Although various methods of cooling have been used, cooling stimulation of muscles may influence the changes in muscle strength and mass. However, many cooling methods used in previous studies were likely clinically unrealistic, and the effects of local cooling performed as an emergency procedure have not been verified. Therefore, continuous application of local ice cooling on injured muscles during sports is expected to suppress muscle weakness and atrophy caused by detraining.

Previous studies on the prevention of muscle weakness and atrophy have used models, such as hind limb suspension or cast immobilization. Blood flow restriction (BFR) without exercise reduces muscle weakness[7,8]. However, it is unknown whether BFR is effective in reducing muscle weakness and atrophy that is caused by detraining. In this study, we investigated the effects of local cooling and BFR on muscle weakness and atrophy that were caused by detraining. This study defined atrophy as that decrease in muscle mass that was caused by detraining after training-induced hypertrophy.

Methods

1. Subjects

The subjects included 11 healthy men without a history of injuries to the upper extremities or severe medical complaints. The subjects were not engaged in any form of regular physical training. This study was approved by the Human Ethics Committee of the Juntendo University. Prior to the experiments, the purpose of the study, contents, experimental protocol, possible risks involved, and management or security offered in case of an accident were completely explained to the subjects, and their written informed consent was obtained.

2. Experimental procedure and design

The subjects performed 6 weeks of elbow flexor training followed by 3 weeks of detraining. During the detraining phase, the subjects received local cooling or BFR; we observed for changes in muscle strength and mass during this period. Subjects were then randomly divided into two groups: those who received cooling by ice bag (ICE condition) and those who received BFR condition. There were six subjects in the ICE condition group (mean age, 23.5 ± 2.5 year; mean height, 172.5 ± 10.0 cm; and mean weight, 78.6 ± 19.9 kg) and five subjects in the BFR condition group (mean age, 24.8 ± 0.8 year; mean height, 171 ± 6.3 cm; and mean weight, 68.4 ± 5.5 kg). The contralateral arm of all subjects (n = 11) did not receive any interventions (CON condition). The dominant and non-dominant arms of the intervention group were randomly assigned to receive local cooling or BFR with the non-dominant arms (n = 5) and dominant arm (n = 6). During training and detraining, the subjects were prohibited intense exercise and upper arm training.

3. Training period

All subjects performed elbow flexor exercise 3 days per week for 6 weeks. The training comprised maximal isometric contractions of the elbow flexor at an elbow joint angle of 90° on a Biodex System 3 dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). Each subject was seated on a chair and his chest and waist were immobilized by straps and the upper arm was placed on a padded support that secured the shoulder joint angle at 45° of flexion and 30°-40° of abduction. The exercise comprised four sets of six isometric contractions held for 5 s, with a 5-s rest in between contractions, and a 1-min gap between sets.

4. Detraining period

After training, the subjects entered a 3-week detraining period, during which they returned to their pre-study daily activity level. In subjects under the ICE condition during the detraining period, one upper arm was cooled by application of an ice bag on the medial side for 30 min/day in the afternoon. The ice bag (23-cm diameter) was filled with ice cubes and was devoid of excess air; the ice bag was fixated to the arm by wrapping. In this study, deep muscle temperature was measured using a deep temperature monitor (CM-210, Terumo, Tokyo, Japan). During 30 min of cooling,

deep muscle temperature was reduced to 15.43 ± 1.24℃ in seven young men.

In subjects under BFR condition, blood flow to the upper limb was restricted by compressing the most proximal end of the arm using a tourniquet (MIZUHO Co. Ltd., Tokyo, Japan); the applied external compressive force was 100 mmHg. A set comprised 5 min of applied BFR followed by 3 min of rest by releasing the compression. Each subject underwent five sets twice a day (morning and afternoon) for 3 weeks[8].

5. Measurements

To evaluate changes in muscle strength and mass, we measured elbow flexor torque and cross-sectional area of the upper arm. Measurements were made at pre-training (Pre); post-training (Post); and after 1 week (W1), 2 weeks (W2), and 3 weeks (W3) of detraining.

1) Muscle strength

Elbow flexor torque under isokinetic and isometric contractions was quantitatively measured using the Biodex System 3 dynamometer. Using concentric contraction, each subject was asked to flex the elbow joint four times at an angular speed of 60°/s (CC60) and 120°/s (CC120). Isometric contractions were performed with the elbow joint flexed at 90° (IM). Each subject continued elbow joint flexion for 5 s with two 10-s breaks in between. The intraclass correlation coefficients for the CC60, CC120, and IM torques were 0.92, 0.96, and 0.89, respectively.

2) Cross-sectional area

Cross-sectional images of the upper arm were obtained by magnetic resonance imaging (MRI) (E-scan XQ; ESAOTE, Genoa, Italy). Starting at the lateral epicondyle, a single cross-sectional plane was imaged at 40% of the distance from the lateral epicondyle to the acromion process of the scapula, according to the Fukunaga method[9]. Transverse scans were performed with conventional T1-weighted spin-echo sequence (TR, 1040 ms; TE, 18 ms; NEX, 2; matrix, 192 × 192; FOV, 160 × 160 mm; slice thickness, 5 mm). To prevent the influence of fluid shifts within the muscle, the subject quietly rested for 30 min before MRI measurement. All MRI data were transferred to a personal computer for analysis using specifically designed image analysis software (OsiriX, 5.8.2, Pixmeo, Bernex, Switzerland).

The elbow flexor muscle was digitally tracked and measured by the same investigator. In this study, the biceps brachii and brachialis were traced as the elbow flexors. Digitizing and area calculation were repeated three times for a single image; the average values were adopted as representative of cross-sectional area. Coefficients of variation of the three measurements were less than 5%.

6. Statistical analyses

All data ware expressed as mean ± SD. Differences among the measurement values before training were evaluated between conditions using one-way analysis of variance (ANOVA). Differences in the condition of each measurement between training and detraining were evaluated using one-way repeated ANOVA. Furthermore, the percent changes calculated from the Pre to the Post-treatment measurements were evaluated using one-way ANOVA. The Post values represented the effect of training, whereas the W1, W2, and W3 values represented the effect of detraining in between conditions. When differences were observed, Scheffe's post-hoc test was conducted. P values less than 0.05 were considered statistically significant.

Results

1. Muscle strength

Before training, there were no significant differences in muscle strength values between conditions. During training and detraining, no significant changes for CC60 and CC120 were observed for all conditions (Figure-1 and 2). IM torque significantly increased after training in the CON condition (Pre, 62.9 ± 16.1 Nm vs. Post, 73.2 ± 19.9 Nm; $p = 0.001$); in the ICE condition (Pre, 66.9 ± 19.7 Nm vs. Post, 75.3 ± 22.5 Nm; $p = 0.001$); and in the BFR condition (Pre, 57.1 ± 10.2 Nm vs. Post, 65.5 ± 10.5 Nm; $p = 0.023$) (Figure-3). There were no significant differences in present changes between conditions (CON, 16.6 ± 11.3%; ICE, 12.5 ± 2.4%; BFR, 15.1 ± 9.6%) (Figure-4).

During the detraining period, IM torque significantly decreased in the CON condition (Post, 73.2 ± 19.9 Nm vs. W3, 64.3 ± 11.6 Nm; $p = 0.012$); however, there were no significant changes in the

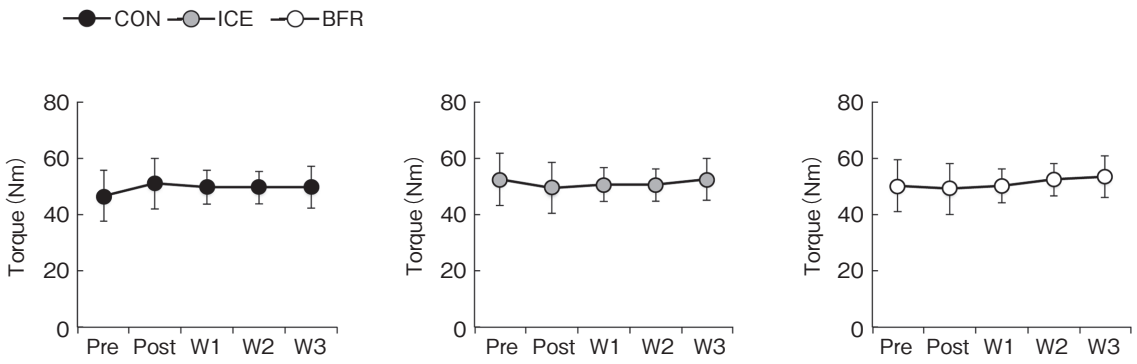

Figure-1 Changes in CC60 (60°/s under concentric contraction) during the training and detraining
Values are mean ± SD. CON condition, n=11; ICE condition, n=6; BFR condition, n=5.

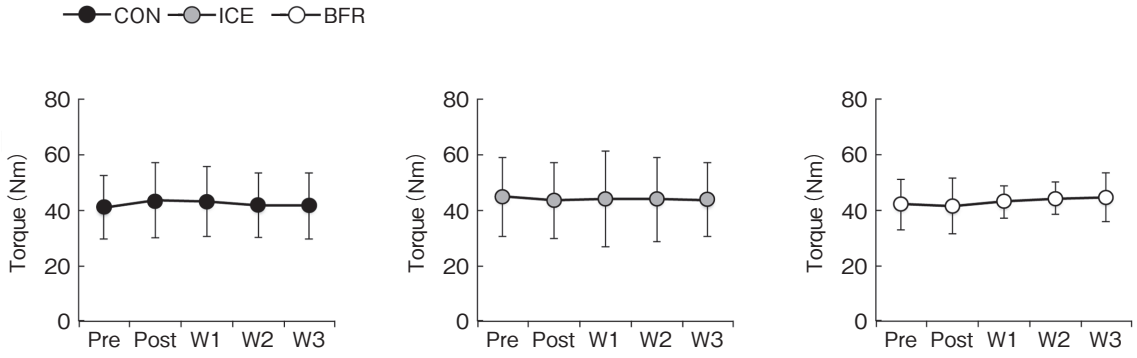

Figure-2 Changes in CC120 (120°/s under concentric contraction) during the training and detraining
Values are mean ± SD. CON condition, n=11; ICE condition, n=6; BFR condition, n=5.

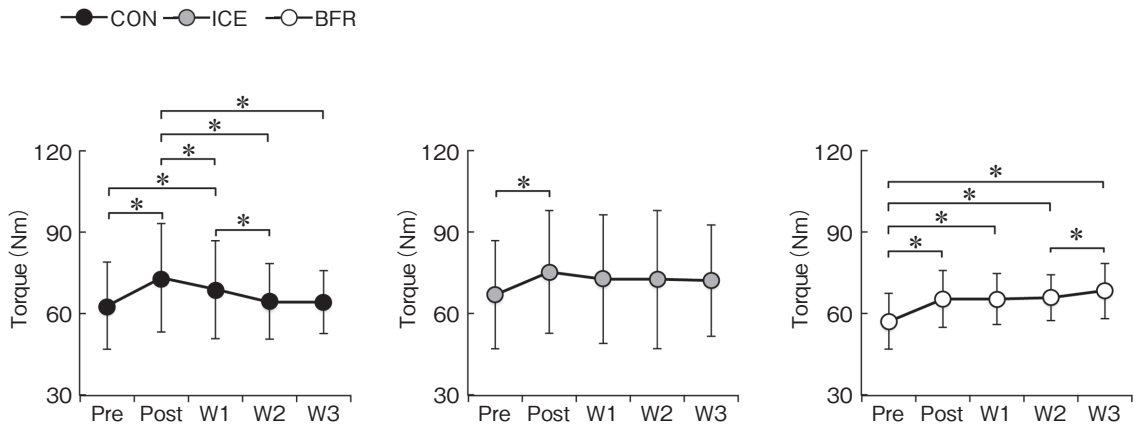

Figure-3 Changes in IM (isometric contraction) torque during the training and detraining
Values are mean ± SD. *p<0.05. CON condition, n=11; ICE condition, n=6; BFR condition, n=5.

ICE condition. However, the BFR condition significantly increased during detraining (W1, 65.3 ± 9.2 Nm vs. W3, 68.2 ± 10.1 Nm; p=0.002) (Figure-3). In the detraining period, the percent change in each condition was significant between CON and BFR conditions at W2 (CON, -13.1 ± 11.3% vs. BFR, 0.9 ± 5.3%; p = 0.029) and W3 (CON, -12.6 ± 11.5% vs. BFR, 4.1 ± 4.2%, p=0.008) (Figure-4).

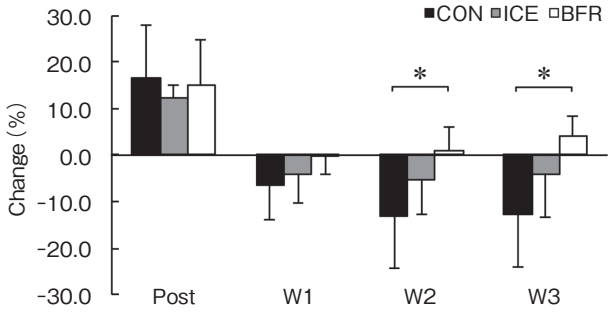

Figure-4 Percent changes in IM (isometric contraction) torque following the training period (Post) changes from Pre; detraining period (W1, W2, W3) changes from Post

Values are mean ± SD. *Significantly different between condition ($p < 0.05$). CON condition, n = 11; ICE condition, n = 6; BFR condition, n = 5.

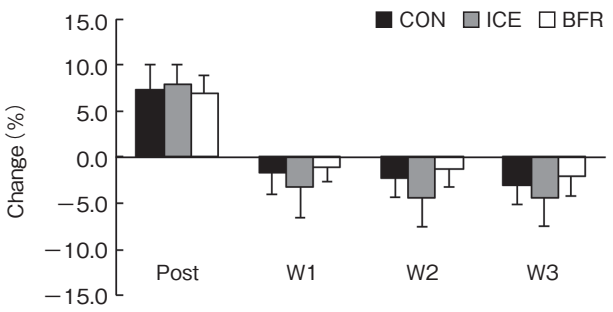

Figure-6 Percent changes in cross-sectional area following the training period (Post) changes from Pre; detraining period (W1, W2, W3) changes from Post

Values are mean ± SD. CON condition, n = 11; ICE condition, n = 6; BFR condition, n = 5.

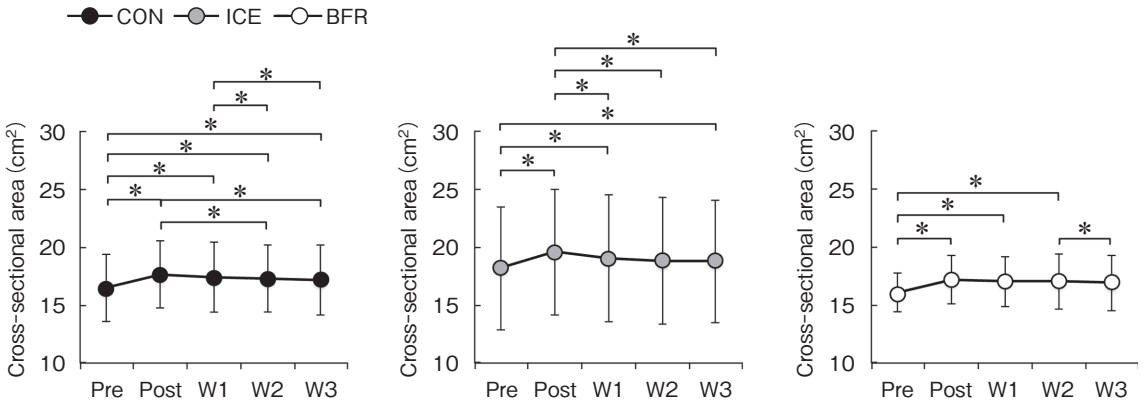

Figure-5 Changes in cross-sectional area during the training and detraining

Values are mean ± SD. *$p < 0.05$. CON condition, n = 11; ICE condition, n = 6; BFR condition, n = 5.

2. Cross-sectional area

Before training, there were no significant differences in the values of the cross-sectional area between conditions. Following training, the cross-sectional area significantly increased at Post compared with that at Pre in the CON condition (Pre, 16.5 ± 2.9 cm^2 vs. Post, 17.7 ± 2.9 cm^2; $p < 0.001$); in the ICE condition (Pre, 18.2 ± 5.3 cm^2 vs. Post, 19.6 ± 5.4 cm^2; $p < 0.001$); and in the BFR condition (Pre, 16.0 ± 1.6 cm^2 vs. Post, 17.2 ± 2.1 cm^2; $p = 0.005$) (Figure-5). There were no significant differences in present changes between conditions (CON, 7.3 ± 2.8%; ICE, 7.9 ± 2.2%; BFR, 6.9 ± 2.1%) (Figure-6). During the detraining period, cross-sectional area significantly decreased at W3 compared with the Post in the CON condition (Post, 17.7 ± 2.9 cm^2 vs. W3, 17.2 ± 3.0 cm^2; $p < 0.001$) and ICE condition (Post, 19.6 ± 5.4 cm^2 vs. W3, 18.8 ± 5.3 cm^2; $p = 0.014$). In the BFR condition, there was a significant difference in muscle cross-sectional area only between W2 and W3 (W2, 17.0 ± 2.4 cm^2 vs. W3, 16.9 ± 2.4 cm^2; $p = 0.004$) (Figure-5). There were no significant differences in percent changes between conditions (CON, -3.1 ± 2.1%; ICE, -4.4 ± 3.1%; BFR, -2.0 ± 2.3%) (Figure-6).

Discussion

In this study, the subjects were made to undergo elbow flexion training with maximum exertion and isometric contraction. No changes were observed in concentric contraction (CC60 and CC120); however, there were significant increases in isometric (IM) muscle strength. Therefore, strengthened

muscle after training resulted from patterns of muscle contraction during training.

Davies *et al.*[10] investigated the outcomes of elbow flexion exercise with 80% maximum voluntary and isometric contractions that were performed three times per week for 6 weeks. The authors found that muscle strength increased by 15% and that the cross-sectional area of elbow flexor muscles increased by 6%. In this study, elbow flexion exercise at a maximum exertion of three times per week for 6 weeks led to approximately 15% increase in muscle strength and approximately 7% increase in muscle cross-sectional area (Figure-4 and 6); these outcomes were similar to previous study. In this study, withholding exercise during the 3-week detraining period resulted in decreased in IM torque by 12.6% and in muscle cross-sectional area decreasing by 3.1% after the training period in the CON condition (Figure-4 and 6).

Isometric muscle contraction is used less frequently in daily activities compared with concentric or eccentric contractions; this may explain our results of a significantly decreased isometric muscle strength, which was previously strengthened through training. Jespersen *et al.*[2] revealed that following 90 days of training, muscle size decreased with detraining; this decrease occurred with an increased expression of myostatin. Therefore, in this study, the expression of myostatin may have influenced muscle atrophy; however, this presumption was not substantiated by biochemical measurements. Furthermore, the atrophy caused by the decrease in physical activity may have been related to differences in muscle fiber type; however, to date, there has been no consensus on this view.

In a previous study, the maximum torque of elbow flexion and cross-sectional area of elbow flexor muscles had a strong positive correlation[11]. In this study, local cooling and BFR were applied during the detraining period and resulted in the suppression of the decrease in maximum muscle strength; however muscle atrophy still occurred. A study has demonstrated that the biceps brachii, brachial, and brachioradial muscles contributed to elbow joint flexion at a rate of 47%, 34%, and 19%, respectively[12]. Furthermore, the round pronator, wrist radial flexor, and flexor digitorum superficialis muscles assisted elbow flexion. Therefore, local cooling and BFR during the detraining period may have influenced the other muscles involved in elbow flexion and possibly suppressed the decrease in muscle strength. Although no significant differences in the rate of change among conditions were observed for muscle atrophy, atrophy was not observed until after 2 weeks of detraining with BFR. This result suggested that BFR contributed to a delay in the occurrence of atrophy.

Williams[13] reported that continuous stretching exercise reduced disuse muscle atrophy. Kubota *et al.*[7) 8)] also suggested that disuse muscle atrophy of the femoral region immobilized with a cast was reduced by external stimuli, such as BFR. These findings indicated that the application of stimuli to the muscle may affect the degree of muscle atrophy.

In this study, BFR was induced using a tourniquet around the base of the upper arm. This method enabled alternate expulsion by compression and reperfusion by decompression as external stimuli to all muscles related to elbow flexion. In contrast, this study applied local cooling on the medial side of the arm with the use of an ice pack of 23 cm in diameter. This enabled the application of local cooling to the biceps brachii and the other muscles involved in elbow flexion. It has been widely studied that local cooling decreases blood flow to affected muscles, whereas the discontinuation of cooling produces vasodilatation and increased blood flow[14)-19)]. Therefore, daily application of local cooling may provide an haemodynamic effect that is similarly to that of BFR. In this study, BFR was performed more frequently than local cooling (twice a day vs. once a day); this may have resulted in greater inhibitive effects of BFR on muscle weakness.

Our results suggested that the control of blood flow by local cooling and BFR suppressed muscle weakness from physical inactivity for approximately 3 weeks. This information would be useful for patient with injury or for athletes. However, we evaluated only muscle strength and mass in this study. In addition, further study is required to clarify the mechanisms of our findings by considering the differences in frequency of cooling and BFR applications and the targeted body site.

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