Adaptive changes in muscular performance and circulation by resistance training with regular cold application

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Abstract

(1) Sixteen male subjects participated in resistance training comprising three sets of 8-handgrip exercises at a workload that could be performed no more than eight times, three times a week for 6 weeks. Eight subjects immersed their experimental forearm in cold water (10\,\textdegree\,C) for 20 min following each training period, while the remaining eight served as controls. (2) Muscular endurance with rhythmic handgrips significantly \((p<0.01)\) increased in both groups after the training period with a non-significant difference between groups. The relative diameter of ultrasonography-evaluated brachial artery failed to increase in the immersion group despite a significant increase \((p<0.05)\) of that in the control group after training. (3) Regular post-exercise cold application might attenuate the improvement in muscular endurance, possibly in association with reduced vascular remodeling.

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1. Introduction

Cold application (ice treatment or cryotherapy) is an effective treatment for acute sports injuries and soft tissue bruising, acting by decreasing tissue temperature, blood flow and inflammatory cell invasion of muscle and thereby inhibiting excessive local inflammatory reactions (Knight, 1995; Thorlacius et al., 1998). Such treatment has also been applied to heal exercise-induced damage following vigorous exercise among athletes. Recently, cold application has been regularly used to facilitate recovery from physical and mental fatigue following exercise in which minimal muscular damage occurs. Knowledge of the physiological basis for the application of this treatment to uninjured muscles would be assumed necessary in order to ensure the effectiveness of athletic conditioning. However, few studies have evaluated the effects of regular post-exercise cold application to uninjured muscles. The authors previously observed that at 4 weeks of resistance training, improvements in local muscular endurance were less pronounced with regular post-exercise application of cold (Teruya et al., 2002).

Although physiological mechanisms to explain our previous results are unclear, local muscular endurance might depend on the metabolic capacity of working muscle cells and/or blood perfusion to working muscles (Andersen and Henriksson, 1977). It is reported that not only aerobic exercise training (Baynard et al., 2003;...
Subjects

Sixteen healthy young male volunteers [age $20.7 \pm 2.3$ years, weight $66.2 \pm 8.8$ kg and height $173.3 \pm 5.6$ cm (mean $\pm$ SD)] participated in this study, after providing written informed consent. Subjects were randomly assigned to one of two groups.

Experimental protocol

The subjects performed three sets of eight-handgrip exercises with their left, non-dominant, hand using a weight-loaded handgrip ergometer at a workload of 30% of maximal pre-training handgrip strength. Brachial artery diameter was measured in the supine position, with the arm in 90° of abduction. The brachial artery was imaged above the antecubital fossa in the longitudinal plane, with diameter measured using a digital arteriometer (ED100N, Yagami Inc., Nagoya, Japan). Local muscular endurance was evaluated by counting the number of handgrip repetitions performed every 2 s until the subject could not tolerate any further contraction at the precise pace using a weight-loaded handgrip ergometer. A metronome was used to precisely pace the handgrip. Subjects performed the handgrip exercise in a supine position at a workload of 30% of maximal pre-training handgrip strength. Brachial artery diameter was measured by ultrasonography (EUB-565, Hitachi Medical Corp., Tokyo, Japan) in the supine position with the arm in 90° of abduction. The brachial artery was imaged above the antecubital fossa in the longitudinal plane, with diameter determined as the distance between the lumen–intima interfaces of the anterior and posterior walls.

Plasma IL-6 and VEGF concentrations were measured by analyzing blood samples taken from the left antecubital vein before, 30, 60, 90, and 120 min after the handgrip training protocol. Blood samples were withdrawn into EDTA-containing tubes and centrifuged, and plasma was stored at $-80^\circ$C until analysis. Plasma concentrations of IL-6 and VEGF were determined by quantitative sandwich ELISA, using a 96-well microtiter plate (BioSource International Inc., Camarillo, CA).
USA). All samples and provided standards were analyzed in duplicate. An ultra-sensitive kit was used for IL-6 detection.

2.4. Statistical analysis

All values are reported as mean ± SD. Differences across the testing conditions were determined by two-way analysis of variance. Significant differences were accepted at \( p < 0.05 \).

3. Results

No subjects experienced muscle soreness or injury during or after the training period. The circumference of the trained forearm tended to increase after training in both groups (from 25.0 ± 1.5 to 25.4 ± 1.7 cm in the control group and from 25.3 ± 1.7 to 25.7 ± 1.8 cm in the immersion group) with no significant differences detected. The maximal handgrip strength in the trained arm did not change significantly in either group over the training period (from 45.1 ± 7.9 to 45.9 ± 9.1 kg in the control group and from 44.3 ± 6.4 to 44.6 ± 6.5 kg in the immersion group). Exhaustion time for repeated handgrip exercise in both arms increased significantly (\( p < 0.01 \)) in the control group and the immersion group after training (Fig. 1A and B). Increase in that of the immersion group tended to be smaller as compared with the control group (nonsignificant difference) after training. Brachial artery diameter in the trained arm showed no significant differences before and after training in both groups (Fig. 2). Left/right (experimental arm/control arm) ratio for brachial artery diameter in the control group significantly (\( p < 0.05 \)) increased, while that of the immersion group did not change (Fig. 3).

Plasma concentration of IL-6 from samples collected at the fourth week of training tended to increase with time after the 3 sets of handgrip exercise in both groups (Fig. 4A). In the immersion group, plasma IL-6 concentration was significantly increased at 120 min after exercise compared to pre-exercise levels (\( p < 0.05 \)). No significant changes in plasma VEGF concentration were observed in response to the handgrip exercise in either group (Fig. 4B). No significant differences in plasma IL-6 or VEGF levels were observed between groups.

4. Discussion

The 6-week program of resistance training with regular post-exercise cold application tended to be shown to inhibit remodeling of the brachial artery. This coincided with the attenuation of improvement in local muscular endurance in response to resistance training.
observed in our previous study (Teruya et al., 2002) and in the present study (nonsignificant tendency). A possible mechanism for these observed changes would be reduced vascular adaptation due to regular post-exercise application of cold, leading to attenuated improvement in muscular endurance. However, the difference in local muscular endurance between groups was less pronounced when compared with that seen in the previous study. In the present study, local muscular endurance showed a similar tendency to improve even in control arms that did not undergo training. Because the subjects in this study were physically untrained, it is possible that a training-induced increase in centrally derived motor activity might have contributed to elevated muscular activity and also obscured the local effect with cold application.

It is possible that attenuated modification of the brachial artery in response to training results in cold-induced vasoconstriction, a decrease in metabolic rate and/or limitation of neutrophil invasion during the recovery period. Reduced blood flow due to the application of cold might decrease biomechanical stress to vascular endothelial cells during the recovery period, which might in turn lessen the stimulus for vascular adaptation. If neutrophil invasion of muscle tissue decreased with cold application, inflammatory reactions promoting vascular adaptation might also be inhibited. However, no physiological evidence was available to support these speculations, as no significant differences were observed in plasma IL-6 or VEGF levels in response to cold application. IL-6 and VEGF levels have been examined in response to systemic exercise in many previous studies. As muscle mass influences the performance of handgrip exercise, it is possible that the workload employed in the present study was insufficient to elicit significant change in plasma IL-6 and VEGF levels. Moreover, it has been reported that neutrophil invasion (Pizza et al., 2002) and VEGF mRNA expression (Gavin and Wagner, 2001; Richardson et al., 2000) in response to exercise, decrease with advancing exercise training. Further studies under different experimental conditions, including increased work load and duration, are needed to ascertain the behavior of these markers in response to cold application during training.

Ice treatment has obvious therapeutic benefits for tissue in which injury is apparent. However, the present results indicate the possibility that regular application of cold, ice treatment or cryotherapy, to uninjured tissue following exercise might diminish anticipated improvements in physical performance. However, because athletes who are already well trained might have smaller reserves for further adaptation, the influence of cold application might be minor. In addition, the type and intensity of exercise varies considerably, with exercise duration tending to be much longer in most training

![Graph](image-url)
programs. Decrease in the exercise-induced stimulus for adaptation due to application of cold might also be minor under conditions of longer exercise duration. In order to apply cryotherapy for conditioning in sports activities, it is valuable to ascertain any potentially disadvantageous effects of such therapy. Further studies are needed to elucidate the mechanisms behind the possible suppression of improved local muscular endurance and vascular adaptation in response to training that utilizes application of cold.

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