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Original Article

The use of a cold pack during resistance exercises is effective for reducing intramuscular oxygenation and increasing myoelectric activity

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Abstract. [Purpose] The purpose of this study was to determine the efficacy of using a cold pack while doing resistance exercises for enhancing muscle strength and muscle hypertrophy through decreased intramuscular oxygenation and/or increased myoelectric activity. [Participants and Methods] Twenty-four resistance-trained males (age: 26.4 ± 8.4 years, height: 169.3 ± 5.2 cm, body weight: 74.7 ± 8.8 kg) involved in this study. All the participants completed two experimental sessions in random order (cold pack resistance exercise and resistance exercise) with a 3-day interval. Four types of resistance exercises (4 sets × 8 repetitions with an 8-repetition maximum) targeting the right triceps brachii muscle were performed in both the experimental sessions. [Results] The percentage baseline oxyhemoglobin/myoglobin level during resistance exercise was significantly lower, the half-recovery time of muscle oxygenation in intervals between sets was significantly longer, and the myoelectric activity was significantly higher in the cold pack resistance exercise than in the resistance exercise session. [Conclusion] The results suggest that using a cold pack with resistance exercises is effective in inducing intramuscular deoxygenation and increasing myoelectric activity and may be useful for increasing muscle strength and inducing hypertrophy.
Key words: Cold pack, Intramuscular hypoxia, Muscle hypertrophy

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INTRODUCTION

Goldberg et al.[1)] reported that increased force development is an essential event in promoting compensatory muscular growth, which has been subsequently confirmed by many studies[2, 3)]. Furthermore, several researchers have proposed that exercise-induced metabolic stress confers anabolic effects, while some have suggested that metabolic accumulation is more important than high-force development for muscle hypertrophy[4, 5)]. In general, to apply greater metabolic stress on working muscles, intramuscular hypoxia caused by resistance exercise is a key element to stimulate the secretion of growth hormones and testosterone in relation to muscle hypertrophy[6)]. Recently, a positive correlation was found between the level of intramuscular hypoxia during resistance exercise and the rate of muscle hypertrophy[7)].

Furthermore, evidence suggests that the pre-treatment cold stimulation of local muscles leads to recruitment of fast twitch fibers[8)] and increases myoelectric activity and isometric contraction force[9, 10)]. Beelen and Sargeant reported a significant increase in steady-state oxygen uptake and blood lactate concentration during cycle exercise with cold-pre-treated lower extremities, presumably due to a relatively high level of muscle hypoxia at the onset of exercise as a consequence of cold-

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induced vasoconstriction[11]. However, direct evidence supporting the efficacy of cold modalities during resistance exercise for reducing intramuscular oxygenation and/or increasing myoelectric activity is limited in the literature.

We hypothesized that resistance exercise while using a cold pack provides sufficient cold stimulation to the muscle and acute effects, such as increasing intramuscular hypoxia and myoelectric activity by recruiting fast twitch fibers; moreover, it is an effective exercise method to increase isometric muscle force and cross-sectional area (CSA). This study aimed to examine the acute effects of resistance exercise with a cold pack on the superficial skin and deep tissue temperature, intramuscular oxygenation, and myoelectric activity.

PARTICIPANTS AND METHODS

To confirm the acute effects of resistance exercise with a cold pack, 24 resistance-trained males (age: 26.4 ± 8.4 years, height: 169.3 ± 5.2 cm, body weight: 74.7 ± 8.8 kg, body fat: 14.6 ± 3.5%) were recruited from members of a resistance weight training club of Aino University. Participants were required to have at least one year of resistance exercise experience and have no illnesses or injuries that may affect their performance. All the participants were familiar with the four resistance exercises examined in this study. The participants performed the same experimental exercise session twice, once using a cold pack and other (regular) without a cold pack, with a 3-day interval in random order. The participants were instructed to refrain from vigorous physical activity within 24 hours of the experimental session[12]. All the participants were informed of the potential benefits and risks of the study both verbally and in writing before signing an informed consent form prior to data collection. The study was approved by the Ethics Committee of Aino University (Aino2019-014) and all participants provided informed consent before participating in the study. The study was conducted according to the standards described by the International Journal of Sports Medicine[13].

To familiarize the participants with the exercises an information session was conducted before the experimental sessions. In both the information and experimental sessions, 10 min of light stretching as a warm-up was performed before starting resistance exercise. After stretching, participants performed four types of triceps brachii resistance exercises continuously in the following order: barbell lying elbow extension, dumbbell French press, dumbbell triceps kickback, and triceps push-down; eight repetitions per set and four sets, with 30 s intervals between sets. The four types of triceps brachii resistance exercises performed in this study were shown in Fig. 1. The exercise intensity was determined at the eight repetition maximum (RM) for each exercise, and not by the % of one RM, because this method is more commonly used during resistance exercise[14].

The average eight RM weight used for resistance exercise was 19.7 ± 2.0 kg in the cold pack group and 19.6 ± 2.3 kg in the control group. Participants flexed and extended their elbow joint using the full range of motion. Eccentric/concentric contraction cycles of the triceps brachii were performed at a metronome-controlled tempo of 1 s per eccentric contraction and 1 s per concentric contraction.

A cold pack (50×30 mm, Kobayashi Healthcare International, Inc. Osaka, Japan) was used in this study as it is readily available and has excellent cold packing effects due to ethanol gel on the surface[15]. Two cold packs, stored in the freezer for at least 1 day before use, were placed on the upper arm, avoiding the deep tissue thermometer probe. The cold pack was fixed to the upper arm with an elastic bandage. The superficial skin and deep tissue temperatures on the right triceps brachii muscle were measured during rest and after all four resistance exercises. The superficial skin temperature was measured by pre-marking the skin on the right triceps brachii long head muscle on the line connecting the right acromion and the olecranon and placing an infrared thermometer 10 cm vertically from that point. The deep tissue thermometer (Coretemp CM-210,

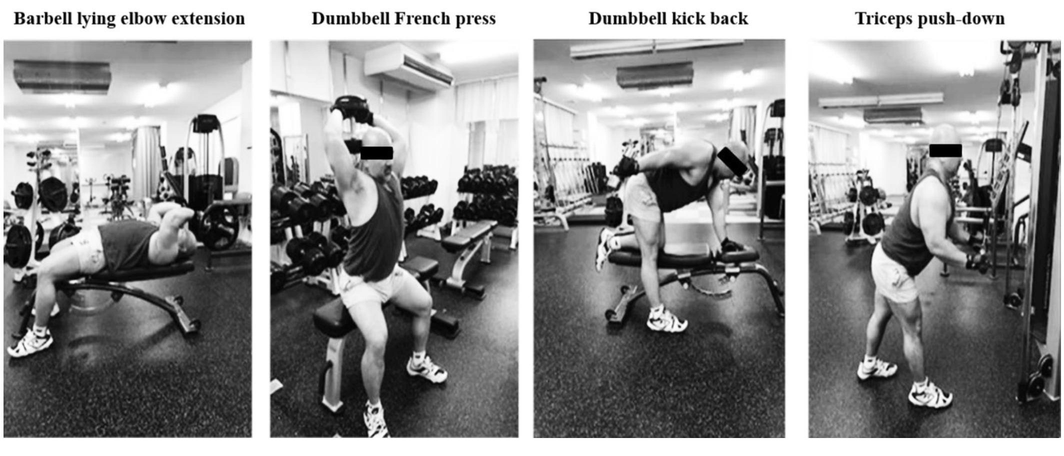

Fig. 1. Resistance exercise protocols.
Four types of triceps brachii resistance exercises were performed in the following order: barbell lying elbow extension, dumbbell French press, dumbbell triceps kickback, and triceps push-down; 8 repetitions per set and 4 sets, with 30-s intervals between sets.

Terumo Inc., Tokyo, Japan) was fixed on the skin above the right triceps brachii long head muscle according to a previous study[16]. For the cold pack exercise, a cold pack was placed immediately after the first superficial skin and deep temperature measurements 5 min after the start of the sitting rest position. The second measurement was performed 8 min after resting and the third was performed 3 min after all the resistance exercises.

The myoelectric activity of the long head of the right triceps brachii was recorded at a sample rate of 1,000 Hz using an electromyogram (EMG) system (Myosystem 1200, Noraxon U.S.A. Inc., Scottsdale, AZ, USA). Bipolar surface EMG electrodes (model: M-150Ag/AgCl, Nihon Kohden Inc., Tokyo, Japan) were used to measure EMG signals from the long head of the triceps brachii during exercise. Based on the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations[17], pairs of EMG electrodes were placed along the muscle midline. The bipolar surface EMG electrodes were placed in line with the muscle fibers with a 2.5 cm center-to-center distance between each pair of electrodes. Prior to placement, the skin was shaved, wiped using skin preparation gel (Nihon Kohden Inc.), and cleaned with alcohol wipes. A reference electrode was placed over the acromioclavicular joint, and it was confirmed that all the recorded inter-electrode resistance values were below 10 kΩ using an electrode impedance checker (Biopack Systems Inc., Goleta, CA, USA). Myoelectric signals were relayed from the bipolar electrodes to a TeleMyo device (TeleMyo 2400T, Noraxon U.S.A. Inc., AZ, USA). The raw EMG signals were rectified, band-pass-filtered, and integrated using a commercially available software (MyoResearch XP, Noraxon U.S.A. Inc., AZ, USA). EMG amplitude was measured from EMG signals: (1) during maximum voluntary contraction (MVC) measurements, the root mean square (RMS) of EMG was calculated based on a 500 ms time window centered on the highest force value; (2) during exercise, the RMS of EMG was calculated for each repetition based on a 500 ms time window centered on the highest value. All RMS values of EMG measurements were normalized to the pre-exercise MVC. The % MVC-RMS of EMG during resistance exercise was compared between the groups.

A near-infrared continuous-wave spectrometer (NIRS: HB14-2; ASTEM Co., Ltd., Kanagawa, Japan) was used to measure peripheral intramuscular oxygenation in the right long head of the triceps brachii muscle during rest and resistance exercise. A typical example of the oxygenated hemoglobin/myoglobin (oxy-Hb/Mb) dynamics in the right long head of the triceps brachii muscle from at rest to the end of resistance exercise is shown in Fig. 2. The wavelength of the emitted light ranged between 750–850 nm and the relative concentration of oxy-Hb/Mb in the target tissue was quantified according to the Beer-Lambert law[18]. The distance between the incident point of the emitted light and the detector was 30 mm. The laser emitter and detector were fixed in place with adhesive tape and the NIRS signals were stored on a personal computer. As the NIRS signals recorded during exercise do not always reflect the absolute levels of intramuscular oxygenation, the changes in the oxygenation of working skeletal muscles were expressed relative to the overall changes in the monitored signal according to the arterial occlusion method[19]. In the present study, the oxy-Hb/Mb level observed at rest was defined as 100% and the minimum oxy-Hb/Mb plateau level induced by arterial occlusion was defined as 0%. A pressure cuff was placed around the proximal portion of the upper arm and manually inflated to 250 mmHg until the minimum plateau level of oxy-Hb/Mb was obtained[20]. The oxy-Hb/Mb level during resistance exercise was compared between the groups and the half-recovery time of muscle oxygenation (T1/2 reoxy time) during the recovery phase of set intervals was measured[18, 21]. The T1/2 reoxy time was calculated as the time for 50% reoxygenation of oxy-Hb/Mb from exhaustion to the 100% level. The calculation method for T1/2 reoxy time is shown in Fig. 2.

All statistical analyses were performed using SPSS for Windows version 27.0 (SPSS Statistics 21.0; IBM, Tokyo, Japan). A 2 × 3 [2 interventions (cold pack exercise vs. regular exercise) × time (rest 5 min, rest 8 min, and 3 min after resistance exercise)] repeated measures analysis of variance (ANOVA), with the Huynh–Feldt correction and Bonferroni pairwise

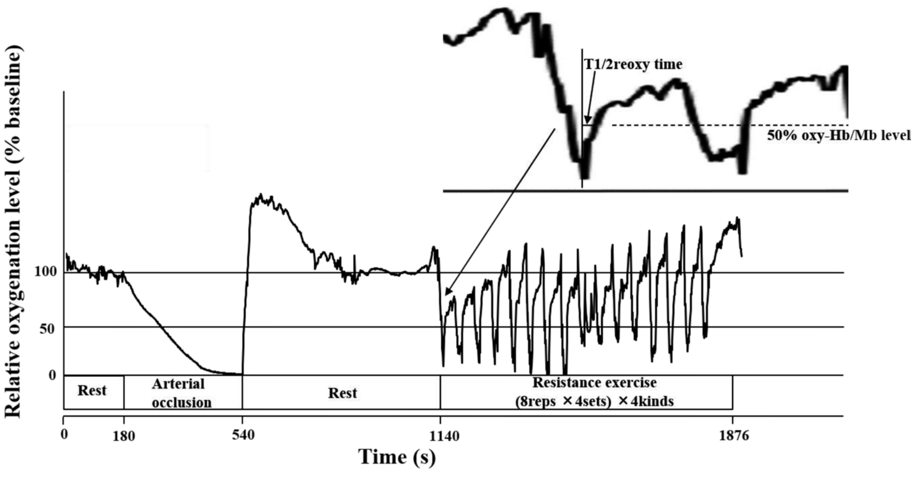

Fig. 2. A typical example of the oxy-Hb/Mb dynamics and method of evaluating the T1/2 reoxy time during the recovery phase of set intervals.

comparisons, was used to analyze the differences in superficial skin and deep tissue temperature. The paired t test was used to compare the differences between cold pack and regular exercises for % baseline oxy-Hb/Mb level, T1/2 reoxy time, and % MVC-RMS of EMG. The results were presented as the mean and standard deviation and an alpha level of 0.05 was used to determine significance.

RESULTS

The superficial skin and deep tissue temperature at 5 and 8 min rest, and 3 min after resistance exercise are shown in Table 1. Both superficial skin and deep tissue temperature 3 min after resistance exercise were significantly higher in the regular exercise than in the cold pack exercise ($p<0.001$).

A typical trend of oxy-Hb/Mb level in the cold pack and regular exercises are shown in Fig. 3. The percentage baseline oxy-Hb/Mb level, T1/2 reoxy time in intervals between sets, and the % MVC-RMS of EMG during resistance exercise between the cold pack and regular exercise are compared in Table 2. The percentage baseline oxy-Hb/Mb level during resistance exercise was significantly lower in cold pack exercise than in regular exercise ($p<0.01$). The T1/2 reoxy time in intervals between sets was significantly longer in the cold pack exercise than in the regular exercise ($p<0.05$). The percentage MVC-RMS of EMG was significantly higher in cold pack exercise than in regular exercise ($p<0.05$).

DISCUSSION

In this study, the pre- and post-resistance exercise superficial skin and deep tissue temperatures, % baseline oxy-Hb/Mb level, T1/2 reoxy time in intervals between sets, and % MVC-RMS of EMG during resistance exercise were compared between the cold pack and regular exercises. The results of this study suggest that the use of a cold pack during resistance

Table 1. The superficial skin and deep tissue temperatures from 5 min rest to 3 min after resistance exercise

	Superficial skin temperature (n=24)		Deep tissue temperature (n=24)	
	Cold pack exercise		Regular exercise	Cold pack exercise
Rest 5-min (°C)	29.8 ± 0.7	29.8 ± 0.5***	30.1 ± 0.9	30.2 ± 0.7***
Rest 8-min (°C)	29.6 ± 0.7	30.3 ± 0.7***	29.9 ± 1.5	30.9 ± 0.9*
3-min after exercise (°C)	30.2 ± 1.8	31.7 ± 1.0ǂǂǂ	30.5 ± 1.2	33.3 ± 0.8ǂǂǂ

Cold pack was applied to the right upper arm 5 min after the start of sitting rest position.
Means ± standard deviation. *p<0.05, ***p 0.001 vs. 3-min after exercise.
ǂǂǂp<0.001 vs. cold pack exercise.

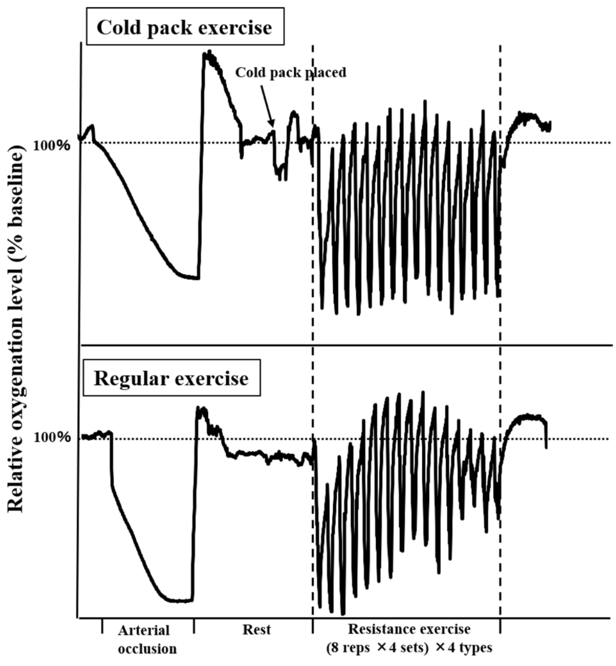

Fig. 3. Typical trend of intramuscular oxy-Hb/Mb level in the cold pack and regular exercises.

Table 2. Percentage baseline oxy-Hb/Mb level, T1/2 reoxytime, and % MVC-RMS of EMG of the long head of the right triceps brachii muscle during resistance exercise

	Cold pack exercise (n=24)	Regular exercise (n=24)
% baseline oxy-Hb/Mb (%)	32.6 ± 6.3	36.3 ± 6.1**
T1/2 reoxy time (s)	5.9 ± 0.7	5.3 ± 0.6*
%MVC-RMS of EMG (%)	72.2 ± 7.0	67.5 ± 7.9*

Oxy-Hb/Mb: oxygenated Hemoglobin/Myoglobin; T1/2 reoxy time: the half-recovery time of oxygenated Hemoglobin/Myoglobin; MVC-RMS of EMG: Maximum voluntary contraction-root mean square of electromyography.
Means ± standard deviation. *p<0.05, **p<0.01 vs. cold pack exercise.

exercise is effective for inducing intramuscular deoxygenation and/or increasing myoelectric activity. The deep tissue temperature 3 min after resistance exercise in the cold pack exercise was significantly lower than that in the regular exercise. This is likely due to the cold pack inhibiting an increase in muscle temperature and hyperemia during resistance exercise. Compared to regular exercise, cold pack exercise had a significantly higher mean % MVC-RMS of EMG, lower % baseline oxy-Hb/Mb level, and longer T1/2 reoxy time in intervals between sets. Muscle stiffness[22)] and motor unit recruitment[8)] may have been promoted by the cold pack, leading to a higher % MVC-RMS of EMG in the cold pack exercise than in the regular exercise. This is in line with a previous study which reported that cooling of the superficial skin approximately doubled the EMG amplitude[9)]. Increased muscle stiffness and motor unit recruitment by a cold pack may promote intramuscular capillary compression during resistance exercise. The lower % baseline oxy-Hb/Mb level during resistance exercise and longer T1/2 reoxy time in intervals between sets in the cold pack were due to high muscular activation.

Goto et al.[7)] compared the effects of resistance exercise on the % MVC-RMS of EMG and intramuscular hypoxia between total range of motion exercise and partial range of motion exercise. They concluded that the myoelectric activity and intramuscular hypoxia during partial range of motion exercise were higher than those during total range of motion exercise, and a higher degree of intramuscular hypoxia resulted in a greater isometric contraction force and muscle CSA after eight weeks, demonstrating a positive correlation. Therefore, long-term continuation of resistance exercise with a cold pack that promotes intramuscular hypoxia may promote an increase in muscle CSA and isometric contraction force.

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Conflicts of interest

There are no conflicts of interest to disclose.

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