J. Phys. Ther. Sci.
22: 43–49, 2010

Changes in Blood Flow, Temperature and Muscle Endurance in Association with Cryotherapy

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Abstract. [Purpose] Sustained isometric muscle actions induce fatigue which manifests as a decline in force. This decline has well known physiological correlates that are often assessed using EMG signal frequency changes, changes in blood flow and muscle temperature. The purpose of this study was to investigate how cooling influences recovery following isometric muscle fatigue. [Methods] Eight healthy volunteers performed isometric elbow flexion to fatigue on two occasions, with 10 minutes of rest with no cooling, 2 minutes and 10 minutes cooling. The surface EMG (median frequency), deep muscle temperature and circulating blood flow were assessed during and after each endurance task. [Results] The 10-minute cooling condition extended endurance in the isometric contraction task. No changes to median frequency EMG signals were detected and the deep temperature and blood flow was most profoundly affected with the extended period of cooling compared to rest and 2 minutes. [Conclusion] This exercise task was enough to induce fatigue in this study. It was shown that 10 minutes cooling for fatigued muscles will extend the duration of subsequent exercise. Indeed, the results of this study suggest the effects of muscle fatigue recovery by cooling are instantaneous.
Key words: Cryotherapy, Fatigued muscles, Duration of exercise

(This article was submitted Aug. 3, 2009, and was accepted Oct. 14, 2009)

INTRODUCTION

Cryotherapy is a physical modality widely used in sports physical therapy practices in Japan and across the world. Cooling can induce many physiological responses. Direct cooling of the skin establishes a temperature gradient and acts to counter the natural heat production of muscles following physical exertion. In addition to generating this temperature gradient the cooling may also generate a powerful local vaso-motor response with initial vaso-constriction followed by secondary vaso-dilation if the cooling is sustained.

It is in a combination of both processes that

Table 1. Physical characteristics of the subjects

Age, yrs	25.6 ± 2.8
Height, cm	176.3 ± 5.9
Weight, kg	70.4 ± 9.7
Arm relaxed, cm	30.5 ± 2.9
Arm flexed and tensed, cm	31.3 ± 3.1
Skinfolds at biceps, mm	4.2 ± 2.1

Values are expressed as mean ± SD. The engineer who had a level 2 ISAK qualification measured them.

cooling also decreases metabolic rate locally, and alters the permeability of capillary vessels. This therefore provides a strong rational for its use in the inflammatory phase of soft tissue injuries. Also, when cells with a high metabolic rate (i.e. muscle cells) may have compromised circulation due to acute trauma and blood vessel damage, then rapid cooling and lowering the metabolic rate may increase the survival rate of some cells.

An additional reaction to cooling is reduction of superficial pain receptors and the inhibition of muscle spindle[1]. Consequently, cooling is also applied to decrease local pain and muscle spasm in both acute and in some chronic conditions. Therefore, cooling has powerful vasomotor and neurological impacts in the pathological setting. However, it is also reported, that decreasing deep muscle temperature changes the maximum voluntary muscle contraction. This has been shown to be dose-dependent when the duration and method of cooling impact on the final deep muscle tissue temperature. Moreover, it is said that direct cooling is more effective for cooling muscles than indirect methods[2,3]. Bergersen et al.[4] suggested that cooling facilitates activity of motor neurons in combination with vasomotor changes, and Swenson et al.[5] reported that cold therapy, as a rehabilitation program, shortens the recovery time from impairments. Early reports have also stated that cooling may reduce the maximum isometric muscle action if it is sustained for a substantial period[6].

In summary, cooling induces significant physiological responses and these responses are dependent on the dose and method of application.

Although the use of cooling is associated with acute trauma and pain, many athletes use icing protocols after sporting events suggesting some additional benefits of cryotherapy. A limited number of studies have examined the role of cryotherapy on recovery of muscle fatigue[7]. These vary from local cooling to whole body cooling tasks (water immersion). Therefore, the purpose of this study was to examine local muscle cooling and determine the impact of different doses of cooling on key physiological parameters of fatigue (EMG median frequency), deep muscle temperature, and tissue circulating volume.

If cooling induces changes in isometric muscle endurance, then examining the physiological correlates (such as temperature and tissue circulating volume and muscle membrane conduction velocity) may assist in identifying some of the underlying mechanisms associated with the dose of the cryotherapy. With this information, strategies to optimize fatigue recovery of muscles may be further developed.

SUBJECTS AND METHOD

To investigate the influences of cooling on fatigued muscle recovery, this study compared three (resting, 2, and 10 minutes cooling) interventions between repeated isometric contraction tasks.

Eight healthy males, mean age 25 years (range from 23–31 years), with no upper limb dysfunction provided their written informed consent to participate in this study. Table 1 shows the anthropometric characteristics of the study population. This study was approved by the Koriyama Tohto Academy Educational Foundation Ethical Committee.

All participants were instructed not to exercise or take caffeine or tobacco products for 24 hours before testing. The ingestion of food and drink 2 hours before the examination was also prohibited. Testing was conducted in a controlled environment with temperatures maintained between 24–26 degrees Celsius and 40% relative humidity with all test participants clothed in a T-shirt and a pair of training pants.

An index of muscle tissue blood flow was determined using a near-infrared ray scanning spectrophotometer (Hamamatsu Hotonikusu Corporation, Niromonitor NIRO-200). The probe was attached on the skin at the right long head of the biceps brachii using double-sided tape. The scanning spectrophotometer measures the total hemoglobin (total-Hb) which reflects the blood volume in deep tissues as previously documented by Jöbsis and Rosenthal[8].

The median frequency (MF) of the surface EMG signal was derived from data collected at 1000 Hz, bandpass filtered at 250 – 500 Hz and post-processed using a Fast Fourier Transformation (FFT). Ten second intervals were recorded at three stages (start, middle and end) of the isometric elbow flexion endurance task. The EMG signal data were recorded from the biceps brachii using bipolar Ag/AgCL electrodes (NIHON KOHDEN Vitrode M-150) with an inter-electrode distance of 30 mm. The electrodes were placed parallel to the fibre orientation of the biceps brachii after skin preparation which resulted in an inter-electrode impedance of less than 5 kΩ.

Coretemp (Terumo Company CM-210) measured the deep-part temperature of the short head of the biceps brachii to the nearest 0.1 degrees C.

The position of the elbow was assessed using an electro-goniometer (HIKARI BELLCOM DAA-1). This device was attached to the arm and forearm.

All participants had the instrumentation attached and were given a period of familiarization with the task required for the experiment. A Maximal Voluntary Isometric Contraction (MVIC) was performed to establish the fatigue load for the endurance task. Participants were then asked to lie supine on the testing plinth for a period of 30 minutes to acclimatize to the test set-up and to stabilise body temperature and blood flow. An additional 5 minutes rest was used as a count down to the start of the endurance task.

The task was an isometric elbow flexion task with participants supine and the shoulder at 90 degree abduction. Participants were required to attempt to maintain their elbow at 90 degrees flexion with a 40% (MVIC) static load. The task was completed when the participant failed to maintain an elbow position of greater than 70 degrees elbow flexion. The duration of the task was recorded to the nearest 0.1 second.

Participants performed the endurance task on a total of 6 occasions (before and after trials for the three different interventions) with consistent encouragement and verbal feedback (Fig. 1). After a baseline acclimatization period participants performed the endurance task. Immediately after the test was ceased the participants extended their elbows into a resting extension position. This was held for 10 minutes during which one of three treatments was applied. The treatments were presented in a random order and consisted of:

10 minutes rest (resting condition)

2 minutes cooling and 8 minutes rest (2-minute cooling condition)

10 minutes cooling (10-minute cooling condition)

Immediately after the 10 minutes rest the endurance task was repeated.

Data recordings continued for an additional five minutes after the end of the second endurance task. Participants were then given at least several days rest before the next phase of testing was undertaken to ensure that full recovery from the endurance task was achieved.

The cryotherapy treatments were provided by a therapist who was experienced in using the jet-type condenser stimulator (Ito, Cryo 5) and the translational method applied to the anterior central brachial surface. During treatment, each participant lay supine on the bed with 90 degrees abduction of the shoulder. The elbow joint resting in a position just short of full extension. The wrist joint was in the intermediate position and the fingers were in their natural position. Participants were instructed to remain as relaxed as possible during rest treatment.

All data are reported as mean (SD) unless otherwise stated. The duration time of the endurance task following each treatment was normalised to the pre-treatment duration time and expressed as a percentage. A decline in duration resulted in values of less than 100%. The normalization was independently performed for each trial. The deep temperature, the blood volume and the median frequency were all normalised to the average value of the T1 testing period (baseline values prior to each endurance trial). The values for the subsequent endurance tasks (T2 and T3) were expressed as a percentage of the baseline value. For all of these outcome variables the assessments during the second endurance task (T3) were determined for the initial (T3-I), middle (T3-M) and last (T3-L) tertiles of the task. This was necessary due to duration differences between individuals.

Using SPSS 11.5J for Windows, 2-way factorial ANOVA was used for statistical analysis, with the level of statistical significance chosen as the 95% ($p<.05$) level of confidence.

RESULTS

Post-treatment exercise duration was significantly lower ($p<.05$) for all rest conditions showing that the 10-minute rest period did not allow

Table 2. The exercise duration ratio

	Before rest	After rest
resting group	100	59.2 ± 11.5†
2-minute cooling group	100	73.1 ± 18.4
10-minute cooling group	100	80.7 ± 12.4*

Values are expressed as mean ± SD.
*:vs resting group After disposal p<0.01. †:vs resting group Before disposal p<0.01.
This figure shows the average exercise duration ratio delete normalized to the pre-rest value each trial (resting, 2-minute cooling, and 10-minute cooling).

for muscle function recovery. The greatest decline in performance was after the 10 minutes resting condition, with a performance of only 59.2 ± 11.5% of the pre-test duration. This was a significantly greater reduction than for the performance following the 10 minutes of cooling (80.7 ± 12.4%) ($p<.001$). A smaller decline in performance was identified after the two minutes cooling (73.1 ± 18.4%) but it was not statistically significant (Table 2).

Table 3 illustrates the normalized temperature recorded every minute for each of the three rest conditions. The standard baseline value did not vary significantly suggesting that the deep muscle temperature had sufficient time to return to baseline levels. The main finding is that there was a carry over effect of increase in deep muscle temperature following the initial endurance task. This was relatively consistent and independent of the rest condition for the first 5 minutes after the first endurance task. At that point, both 2-minute and 10-minute cooling started to induce declines in the temperature. The 2-minute cooling intervention had ceased 3 minutes prior to this noticeable change. Continuous cooling was seen in the 10-minute cooling group which was maintained through the next endurance task and the temperature only started to increase in the first minute of the next recovery period.

Table 3 lists the mean tissue circulating volumes for every one minute. During the endurance task circulation levels were relatively consistent. Following the endurance task, there was an immediate and large increase in circulating volume under all resting conditions. However, circulating volumes were reduced under both the cooling conditions with a clear dose response for the 10-minute cooling condition compared to the 2-minute and the resting conditions. During the second endurance task the 10-minute cooling condition resulted in smaller circulating volumes compared to the other two treatment conditions. During the second endurance task, the tissue circulating volume was still lower after the 10-minute cooling condition than in the other treatment conditions.

The FFT-Median was assumed to be 100% at the onset of the first endurance task. FFT-Median during the first and second endurance tasks was expressed as a percentage of this initial value (Table 4). The surface EMG showed decreases with the progression of each endurance task, but there were no significant differences between the endurance tasks related to the rest conditions.

DISCUSSION

The purpose of this study was to examine the responses to different cryotherapy treatments in a on repeated isometric elbow flexion task.

The first finding was that if continuous cryotherapy was applied during a 10-minute rest period then the duration of performance was significantly increased compared to rest with no cooling. There was a tendency for 2-minute cooling to also extend endurance suggesting that there was a cooling dose effect on the performance of repeated isometric elbow extension. The mechanisms that explain this increase in endurance are multi-factorial, so we examined three main physiological factors that have been proposed as being associated with fatigue or improvement endurance capacity.

The median frequency (MF) of the isometric EMG signal was assessed at three stages in all the endurance tasks. This derived variable is related to muscle fatigue and reflects the conduction velocity of the muscle fibre membrane. We found that during each endurance task the MF declined at the same rate, independent of the duration of the task. This was shown previously by Allison and Fujiwara[9] who reported the decline in the MF reflecting fatigue is independent of the muscle capacity to generate force, and recovery to the initial MF occurs more rapidly than the muscle capacity. The present study did not find any significant impact on the rate of decline or initial MF induced by any of the resting conditions.

We chose an isometric muscle contraction task for observing the muscle fatigue, to focus on the duration of the muscle endurance. Previous researchers have measured the responses of the

Table 3. Deep part temperatures and tissue circulating volume

	Deep part temperatures			Tissue circulating volume		
	RG	2CG	10CG	RG	2CG	10CG
SV	0	0	0	0	0	
T1-I	0.03 ± 0.09	0.05 ± 0.09	0.03 ± 0.13	–2.3 ± 1.7	–3.4 ± 2.3	–0.5 ± 2.2
T1-M	0.03 ± 0.13	0.07 ± 0.14	–0.01 ± 0.27	2.1 ± 1.9	1.7 ± 2.3	1.2 ± 3.4
T1-L	0.12 ± 0.14	0.13 ± 0.18	0.04 ± 0.35	5.4 ± 1.7	2.1 ± 2.5	2.6 ± 2.8
T2-1	0.21 ± 0.25	0.23 ± 0.19	0.23 ± 0.42	16.1 ± 2.9	15.1 ± 3.0	13.4 ± 3.0
T2-2	0.29 ± 0.33	0.36 ± 0.20	0.43 ± 0.49	14.7 ± 2.7	12.5 ± 3.1	11.2 ± 3.0
T2-3	0.38 ± 0.37	0.41 ± 0.22	0.52 ± 0.51	12.8 ± 2.6	9.2 ± 3.0	8.4 ± 2.8
T2-4	0.46 ± 0.38	0.40 ± 0.25	0.54 ± 0.51	11.1 ± 2.4	7.2 ± 2.9	6.0 ± 2.7
T2-5	0.53 ± 0.37	0.39 ± 0.26	0.50 ± 0.51	9.6 ± 2.3	5.9 ± 2.8	3.3 ± 2.6
T2-6	0.58 ± 0.37	0.40 ± 0.27	0.42 ± 0.51	7.9 ± 2.2	4.9 ± 2.7	1.0 ± 2.8
T2-7	0.61 ± 0.36	0.41 ± 0.28	0.31 ± 0.52	6.8 ± 2.0	3.8 ± 2.6	–0.8 ± 2.9
T2-8	0.64 ± 0.36	0.43 ± 0.28	0.20 ± 0.54	5.9 ± 1.9	3.5 ± 2.4	–1.5 ± 2.8
T2-9	0.66 ± 0.35	0.45 ± 0.29	0.08 ± 0.56	4.9 ± 1.7	2.9 ± 2.3	–3.1 ± 2.8
T2-10	0.67 ± 0.35	0.46 ± 0.29	–0.04 ± 0.57	4.3 ± 1.6	2.1 ± 2.4	–3.4 ± 2.8
T3-I	0.68 ± 0.35	0.47 ± 0.28	–0.19 ± 0.60	–2.0 ± 1.8	–4.1 ± 2.3	–9.0 ± 3.0
T3-M	0.69 ± 0.36	0.47 ± 0.29	–0.37 ± 0.70	–0.9 ± 1.8	–2.1 ± 2.4	–7.3 ± 3.0
T3-L	0.67 ± 0.36	0.48 ± 0.30	–0.52 ± 0.76	1.0 ± 1.8	0.0 ± 2.5	–4.8 ± 3.2
T4-1	0.70 ± 0.39	0.53 ± 0.32	–0.71 ± 0.89	12.8 ± 2.7	13.7 ± 2.9	6.4 ± 3.1
T4-2	0.75 ± 0.42	0.60 ± 0.34	–0.59 ± 0.71	11.3 ± 2.6	12.5 ± 2.9	6.5 ± 3.2
T4-3	0.80 ± 0.43	0.65 ± 0.36	–0.46 ± 0.64	9.6 ± 2.4	11.1 ± 2.7	5.8 ± 3.1
T4-4	0.85 ± 0.43	0.69 ± 0.37	–0.36 ± 0.63	8.4 ± 2.2	9.9 ± 2.6	4.8 ± 3.0
T4-5	0.88 ± 0.42	0.74 ± 0.38	–0.27 ± 0.63	7.3 ± 2.1	8.7 ± 2.5	4.3 ± 2.8

Values are expressed as mean ± SD. SV: the standard value. RG: resting group. 2CG: 2-minute cooling group. 10CG: 10-minute cooling group.

Table 4. FFT-Median ratio of the EMG at the biceps

	Before			After		
	T3-I	T3-M	T3-L	T3-I	T3-M	T3-L
resting group	100	61.5	49.3*	99.1	63.9	54.4†
two minutes cooling group	100	69.1	57.3*	105.6	73.7	58.3†
10 minutes cooling group	100	64.1	49.0*	98.1	62.3	51.2†

Values are expressed as mean. *:vs Before T3-I $p<0.01$. †:vs After T3-I $p<0.01$.

peripheral limbs. We selected the upper arm for observing the responses, because we thought it would more useful in clinical practice. The depth of cutaneum may influence the cooling effects, therefore the depth of sebum was measured using the International Society for the Advancement of Kinanthropometry (ISAK) which is based on an international standard. The depth of sebum at the upper arm around the biceps muscle was thin, indicating that the upper arm is suitable for measuring the effect of cooling.

As a definition of muscle fatigue during an exercise task, we could observe the following three things[10,11]:

A decrease in muscular strength;

EMG activity (amplitude and frequency) was increased when maintaining the load at constant tension.

It is assumed that as muscle fatigue progresses, the EMG power spectrum moves to a lower frequency band.

The task was a continuous isometric contraction of elbow flexural retention at 40% MVC of each participant. Continuous flexion of an elbow joint becomes impossible, so even though a change in the FFT-Median ratio could be identified, we consider it was sufficient exercise to develop muscle fatigue under all three resting conditions. Also, from the exercise duration ratio, a decrease in muscle fatigue at pre-exercise and post-exercise in the resting condition was observed, showing that muscle fatigue due to the exercise task was not improved by resting for only 10 minutes. The post-treatment exercise duration ratio was significantly improved under the 10-minute cooling condition, but not for the resting condition, suggesting cooling results in immediate improvement of muscle endurance. However, since there were not significant differences among the FFT-Median ratios. For the three rest conditions, we think there was no big difference muscle fiber changes in each rest condition. Therefore, by improvement in the exercise duration ratio was not due to physiological muscle fatigue, and we presume that the extension of exercise endurance was the result of lowering the myogenic pain through cooling. Moreover, Blair[12] reported that oxygen and energy consumption in cells decline because of decreases in cell metabolism induced by cooling. Cells may work normally even if the blood supply is decreased because their metabolism is inhibited. Therefore, cooling the muscle may lead to reduction of oxygen and energy consumption resulting in extension of the muscle endurance. Moreover, Hunter[13] reported that cooling reduces the speed of motor movement as a result of increasing the stickiness and joint resistance. In addition, Clarke et al.[14] that decreasing the temperature of the forearm increased the mechanical stickiness of muscles, which they suggested was the result of raising the stickiness of the muscle fibers. Tissue stickiness increases the resting tension, hence the stickiness effect would have worked positively to extend the duration of the isometric contraction task in this study.

In the deep temperature graph, an increase of deep part temperature due to muscle activity can be seen post-exercise. Recovery of muscle temperature was mild only in resting, and was not improved in minutes because of the temperature decreases of cooling from the outside that then transmitted into the tissue. Therefore, it can be confirmed that a certain time interval is required for recovery of both the 2 minutes cooling and the 10 minute cooling condition. The effect of the short-term cooling was small, but the10 minutes cooling results indicate the stability of the effectiveness will be longer. A period of duration is thought to be required for expanding the cooling effect from the outside of the body thorough the tissue. Bierman and Friedlander[15] confirmed that there was no change of the temperature in deep tissue induced by cooling for a few minutes, and the cooling effect to deep tissue delays. Lowden and Moore[16] reported a positive relationship between the amount of cutaneum and the cooling effect on deep tissue. In this study, we cooled down the centre of the upper arm. The cutaneum of the upper arm is comparatively thin; thus, a cooling effect was observed. Furthermore, from the start of the endurance task, deep tissue temperature increased in the both condition. Twenty per cent of basal metabolism is accounted for by heat production in muscle activities, and it accounted for several fold heat production during the endurance task. We think the rising deep temperature after exercise is the result of the muscle activity. These results imply that when using cooling therapy, it is necessary for therapist to measure the thickness of the cutaneum and think of the differences of the part of the body, sex, and body type.

For the tissue circulating volume, temperature changes similar to those of the deep part temperature were observed. It was apparent that the blood flow decreased during the endurance task. We concluded that muscle contraction caused by the physical action compressed the arteriovenous blood vessels. In addition, a significant increase of tissue circulating volume was seen after the exercise, indicating that blood vessel pressure had been removed. Subsequently, we think that circulating volume increased because of oxygen supplementation. This suggests that the tissue circulation volume strongly influences the deep part temperature.

We demonstrated a cooling effect on muscle endurance, though, further research is needed to clarify the mechanisms involved.

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