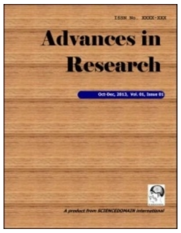

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Effect of Cold Wraps on Muscle Recovery after Exercise Induced Muscle Soreness

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: Numerous studies have been conducted on the effects of cold on muscle soreness; however, few agree on the measureable benefits of cold after exercise. Different studies apply different temperatures to the skin, for different lengths of time, and then differ greatly in how the effects of cold are evaluated. The purpose of this study was to assess the effect of a standardized cold wrap (0ºC) applied immediately or 24 hours after exercise. The effect of cold applied over muscle was evaluated with both subjective and objective measures.
Study Design: longitudinal study
Place and Duration of Study: Physical Fitness Laboratory, Department of Physical Therapy, School of Allied Health Professions, Loma Linda University (LLU), California, U.S.A. between March 2013 and May 2013.
Methodology: Three groups of 20 subjects with an age range, 20-40 years conducted leg squats in three 5 minute rounds to cause delayed onset muscle soreness; 3 minutes of rest separated the rounds. One group had cold wraps applied immediately and a second group had cold wraps applied 24 hours after exercise. A third group was the control group. The effect of cold was measured by a visual analogue pain scale, muscle strength of the quadriceps muscles, knee range of motion, stiffness of the quadriceps, Algometer

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to measure quadriceps soreness, and electrical resistance of the leg.
Result: One of the most significant outcomes was a reduction in soreness in the group that had cold wraps applied immediately after exercise (p <0.01). Cold immediate helped reduce damage to the quadriceps after heavy exercise. Cold was not just cool water, but cold wrap, a form of cooling capable in a short time of reducing deep tissue temperatures.
Conclusion: These data support using cold immediately after exercise to reduce muscle damage but not hours or days after exercise.

Keywords: Cold; exercise; muscle; soreness.

1. INTRODUCTION

In various sports and activities, if the level of exercise is greater than that normally encountered, it is common to have stiffness and soreness that begins 1-2 days after exercise [1]. This soreness, called delayed onset muscle soreness or DOMS, is characterized by decreased range of motion of the joints [2], celular inflammation [3] decreased muscle strength [4] and increased concentrations in the plasma of intramuscular constituents such as Myoglobin [3]. Balance has also been shown to be altered in people who have DOMS [5]. Because DOMS discourages exercise and often follows clinical therapeutic exercise programs [6], there have been numerous studies on the means of reducing DOMS. If a treatment modality can be applied to damaged muscle to reduce damage, pain and loss of function [7,8], it will allow people to exercise more frequently and follow home exercise programs in a clinical setting with better compliance. The modalities usually used include heat, massage, diathermy, contrast baths, cold hydrotherapy, ultrasound and cold packs.

Cryotherapy (cold therapies) has been accepted by many as a means of reducing tissue damage and inflammation and is usually used after sports related injuries [9,10]. Cold is used commonly even as a preventative measure for muscle damage in athletic teams [11]. However, research on the use of cold to reduce muscle micro trauma is sparse.

The concept in using cold is that cold should reduce swelling and slow metabolism so that edema and injury are reduced [12]. Cold also has been shown to reduce pain and therefore has a duel and beneficial role [13,14]. However, the evidence is controversial. Some studies show no beneficial effects of either cold and hot contrast baths or cold water immersion immediately after exercise while others show a reduction in pain and preservation of muscle function [8,11,15]. Vaile, for example, determined that contrast baths were superior to cold used alone in reducing muscle soreness and preserving strength when compared to cold hydrotherapy but details on how he measured DOMS was absent and therefore this study is unreliable [16]. Other studies show no effect of cold in reducing DOMS at all [17]. This is not surprising since measures of deep tissue temperatures in the thigh show that contract baths change skin but not deep tissue temperatures [18,19]. Higgins compared 2, 5 minute bouts of cold water immersion to contrast baths and found a reduction in pain. While this study was conducted with more rigor than previous studies, its measure of muscle strength was the ability to jump high a measure that combines flexibility with strength and did not isolate the effect of exercise and cold application on either alone [7].

In a study of squats used to induce muscle soreness, cold water immersion was used for 72 hours post exercise. There was no change in analytes such as myoglobin in the cold immersion group when compared to the control group. Perceived pain did improve as did recovery of isometric strength after in this DOMS study [20]. The authors however used immersion of the legs. As they correctly stated, this causes, in itself, an increase in tissue hydrostatic pressure and may be responsible for reduced edema and swelling independent of the cold that they applied. They did not use a control group with room temperature water to see the effect of hydrostatic pressure on tissue alone compared to the effect of cold. Applying ice alone would have resolved this issue.

But in a study of the biceps, after muscle soreness was created, there was no effect of ice massage on muscle analytes such as myoglobin. The authors concluded that ice massage immediately and 24 and 48 hours post exercise were ineffective in reducing the symptoms of DOMS [21].

In another recent study, [12] cold water immersion was at 15ºC and was administered after leg exercise and at 24, 48 and 72 hours post exercise. They found no effect of cold water immersion on the first bout of exercise but found benefit days later. They concluded that the use of cold water baths remains unclear.

A major problem in these studies is that the cold water or wraps that were used were at widely different temperatures and exposure was for different lengths of time. While some people used immersion, also increasing tissue hydrostatic pressure, others used ice. The means of determining relief from DOMS were also variable and many studies simply self-reported the effectiveness of pain relief. Therefore, in the present investigation, a more systematic study was accomplished to look at both self-reported and subjective measures of muscle soreness and stiffness with ice wraps applied to the legs of subjects post exercise to see if pain and muscle damage could be reduced.

2. MATERIALS AND METHODS

2.1 Subjects

The subjects for this study were 60 healthy individuals between the ages of 20 and 40 years old, divided randomly into 3 groups of 20 subjects. The groups were 1) control, 2) ThermaCare cold packs immediately after exercise and 3) ThermaCare cold packs applied 24 hours after exercise. All subjects had at least six weeks of physical inactivity in the upper body and their body mass index (BMI) was less than 40. Subjects had no cardiovascular disease, hepatic disease, diabetes, lower limb neuropathies, or recent lower limb injuries. Subjects were not taking alpha or beta agonist/antagonists, any type of Non-steroidal anti-inflammatory (NSAID), Cox 2 inhibitors, calcium channel blockers, Pregabalins (Lyrica), or pain reducers. The demographics of the subjects are shown in Table 1. All methods and procedures were approved by the Institutional Review Board of Loma Linda University and all subjects signed a statement of informed consent.

2.2 Measurement

2.2.1 Muscle strength measurement

Muscle strength was measured with a strain gauge transducer, which used four strain gauges placed on opposite sides of a steel bar. The bar was fixed to a chair base with a leather ankle strap that was placed just above the malleolus and measured force developed during extension of the quadriceps muscle with the knee bent at 90 degrees. When the bar was bent, the strain gauges, arranged as a Wheatstone bridge, were deformed and an electrical output was provided to a BioPac (BioPac Systems, Goleta, CA) system DAC100 bioelectric amplifier module. The signal was amplified 5,000 times and then digitized through a BioPac MP150 analog to digital converter at a resolution of 24 bits and a frequency of 1,000 samples per second and stored it digitally for later analysis. Data analysis and storage were accomplished using the Acknowledge 4.1 software from BioPac Inc. (BioPac Systems, Goleta, CA). Muscle strength was determined on two occasions as a maximum isometric contraction, with each contraction lasting for three seconds in duration with at least one minute of rest separating the contractions. The average of the two strength measurements was used in the data analysis as the subject's maximum strength.

Table 1. Mean (SD) of demographics of subject groups

	Control group (n=20)	**Cold immediately exercise (n=20)**	**Cold 24 hours after exercise (n=20)**	**p-value***
Age (years)	25.3 (3.0)	25.5 (2.7)	26.1 (2.8)	0.61
Height (Cm)	165.9 (6.0)	174.4 (9.2)	170.3 (8.6)	0.01
Weight (Kg)	63.7 (10.4)	67.2 (12.4)	74.1 (26.6)	0.18
BMI(Kg/m^2)	23.1 (3.5)	22.0 (2.5)	25.3 (7.8)	0.12

**One-way ANOVA*

2.2.2 Subjective pain measurement

A 10 cm visual analog scale was used. It had a horizontal line across a piece of paper 10 cm long. One end was marked "pain free" and the other "very, very sore". The subject was asked to place a vertical slash across the line where appropriate. The location of the slash was converted into a number, where 0 indicated pain free and 10 indicated very, very sore. Only one visual analog pain scale was printed on a single sheet of paper.

2.2.3 Ligament elasticity

Elasticity of the anterior cruciate ligament was measured by a kinematic knee device which is commercially produced and has been validated in numerous studies. The device was the Medmetric KT2000 (Medmetric Corporation, San Diego, CA). The subject lay supine with the angle of the knee at 25-30 degrees. A strain gauge measured the force necessary to generate an anterior/posterior glide of the proximal end of tibia on the femoral condyles thus generating a force curve of elasticity of the anterior cruciate ligament (ACL).

A foot positioning device and thigh strap was used to position the leg of the subject. Force was applied for the anterior cruciate ligament at 15, 20 and 30 lbs. (66.6, 88.8, 133.2 Newton's, respectively). As force was applied, the force and measured displacement were plotted on an x-y plotter to record the ligament elasticity. The device has been well validated and published [22-24]

2.2.4 Force to flex and extend the knee (FK)

The force to flex and extend the knee was measured from 90 to 125 degrees. The subject was in the seated position with the leg free to hang at an initial angle of 90 degrees with the foot off of the floor. A linear actuator was connected through an ankle strap to passively move the knee through 35 degrees of flexion. The force needed to move the knee was measured as a measure of the flexibility and elasticity of the quadriceps muscle and its tendons. The rate of movement was 45 degrees in 7.5 seconds. The knee was flexed and then extended and the force was measured in each direction. Resistive strain gauges (350 ohms) were arranged as a Wheatstone bride. The bridge output was amplified and conditioned with a DAC100 strain gauge amplifier with a gain of 500 (BioPac Systems, Goleta, CA). The amplified output was digitized at 2000 Hertz with a resolution of 24 bits on an MP150 BioPac data acquisition system (BioPac Systems, Goleta, CA). A goniometer measured the angle of the knee to calculate the force needed per degree moved. The goniometer used a ruby bearing 360 degree 5000 ohm potentiometer. Its output was amplified and digitized by the BioPac system as described above.

2.2.5 Measurement of skin resistance

Electrical resistance was measured from a prototype device from Mettler Electronics (Anaheim, CA) called a Zone Finder. It supplied a constant 9 volts between two probes to measure the micro current in micro amps between the electrodes, generally measuring around 100 micro amps. The two probes were tipped with cotton pads and mounted in housing where the distance between probes could be changed, and the force of each probe on the skin could be measured on two separate force gauges. Due to the angle of the probes, pressure caused the skin between the probes to stretch. During each test, the cotton pads on the probes were first soaked with 0.9% saline. Then they were placed onto the subject so that equal pressure was applied on each probe, as measured by each force gauge. Only then would the current be recorded. Also, the skin was first cleaned to minimize the effects of dirt, sweat, or anything else on the surface of the subject. Skin current was measured at 9 locations above the quadriceps in each leg and the data shown in the figures is the average of 18 measurements.

2.2.6 Measurement of range of motion

Range of motion of the knee was measured by a trained physical therapist with a digital goniometer. Measures were made of full active range of motion and the point during range of motion of the knee where pain was felt, if any, after the exercise.

2.2.7 Measurement of pain threshold

The minimum pressure that induces pain in tender and trigger points of tissue were measured with an Algometer (Wagner model FPX, Greenwich, CT). The Algometer quantified the pressure it took over a defined surface to produce pain in the belly of the quadriceps muscle. It measured pressure with 10 gram sensitivity and the location used was 40% of the distance from the top of the patella to the anterior superior spine of the hip. The point was marked the first day with a marker so that measurements could be repeated. The surface area of the Algometer tip was 52.5 square mm.

2.2.8 Exercise

All subjects participated in the same exercise to induce DOMS in the lower body. To provoke DOMS, the subjects accomplished squats as fast as they could for 5 minutes. They repeated the exercise after 3 minutes of rest two more times (total 3 rounds). The depth of each squat was at 90º or below.

2.2.9 Cold Therapy

Cold was applied by placing 1 ThermaCare cold wrap on each leg centered over the quadriceps and lying longitudinally over the muscle. Packs were left on for 20 minutes and were at 0ºCat the start of application.

2.3 Procedures

On each day, subjects entered the room and relaxed in a thermally neutral environment for 20 minutes. Measurements such as leg strength, range of motion, tissue resistance, analogue visual pain scales, ACL laxness, and force to move the leg were recorded. These data were collected on a Monday, exercise was accomplished on Tuesday and then measurements were measured again on Wednesday, Thursday and Friday. The only difference between the groups was that one was the control and did not have cold applied; one had cold applied by ThermaCare cold wraps immediately after exercise and another group had ThermaCare cold wraps applied 24 hours post exercise. ThermaCare cold wraps were placed on the long axis of the quadriceps bilaterally for 20 minutes.

2.4 Data Analysis

Data were summarized using means and standard deviations (SD). One-way analysis of variance (ANOVA) was conducted to compare demographics of the three groups. For all data collected over the time within each test, a mixed factorial ANOVA was used to test for differences among groups in muscle strength, pain scale, knee flexion pain, skin current, force to passively move the leg and knee ligament laxness. The level of significance was set a $p<.05$.

3. RESULTS AND DISCUSSIONS

3.1 Results

3.1.1 Muscle strength

As shown in Fig. 1, there was a reduction in strength the day after the exercise in the control group. This significant reduction ($P<.01$) was 23.8% less than the resting (pre exercise) strength. Strength was still significantly lower in the cold immediate group compared to the resting data at 1, 2 and 3 days post exercise ($P<.01$). For the group that had cold applied at 24 hours post exercise, there was a reduction in strength 1 day post exercise and 2 days post ($P<.01$) but no reduction in strength that was significant ($P = .09$) 3 days post exercise. The cold immediate group had the least reduction in muscle strength after exercise for the 3 groups.

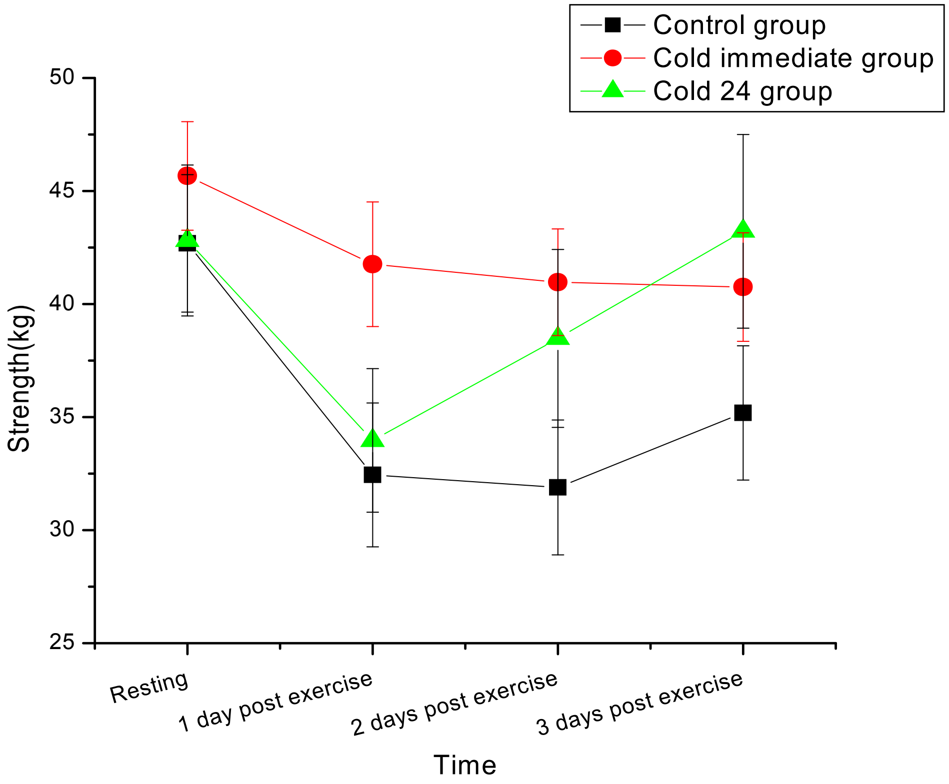

Fig. 1. The measured strength in the quadriceps muscles in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

3.2 Pain Scale

The results of the pain scale determination are shown in Fig. 2. As can be seen in this figure, all subjects showed an increase in pain after the exercise. The pain peaked by 2 days post exercise. The increase in pain in all groups was significantly higher than rest at days 1, 2 and 3 post exercise (P = .02). The least pain was felt 1 day post exercise and was in the cold immediate group. Pain was significantly higher at 1 day post exercise in the cold 24 and control groups than the cold immediate group (P<.01). Pain was not different 1 day post exercise in the control and cold 24 groups. But by the 2nd day post exercise, pain was significantly less than the control group in the cold 24 group (P<.01).

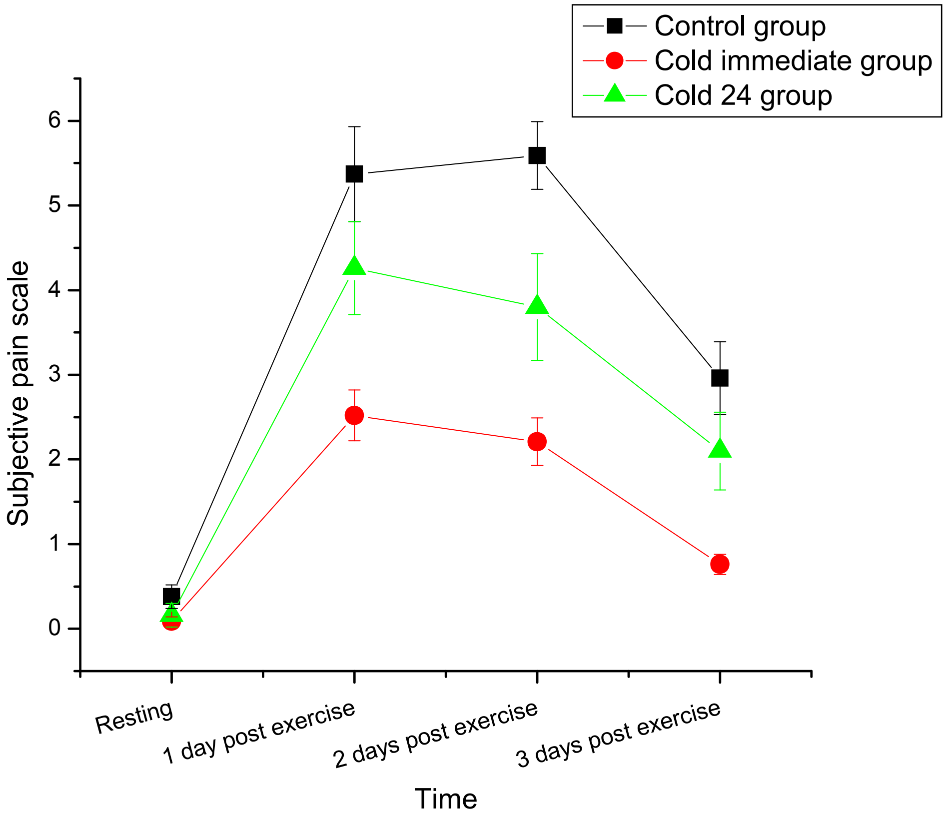

Fig. 2. The measured visual analog pain scale of the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

3.3 Knee Flexion Pain

The knee was passively flexed through full range of motion and the point where, if any, pain was felt was recorded. The results are shown in Fig. 3. As can be seen here, there was pain felt on flexing the knee at less than full range of motion on the 1^{st}, 2^{nd} and third day post exercise for all three groups of subjects. The decreased range of motion at which pain was felt was significant comparing it to the resting data for all 3 groups at days 1 and 2 post exercise (*P* =.02). But the reduction in the 2 groups using heat was only a few degrees whereas the reduction in the control group was over 10 degrees and was significantly more than the other 2 groups at days 1,2 and 3 post exercise (*P* =.03).

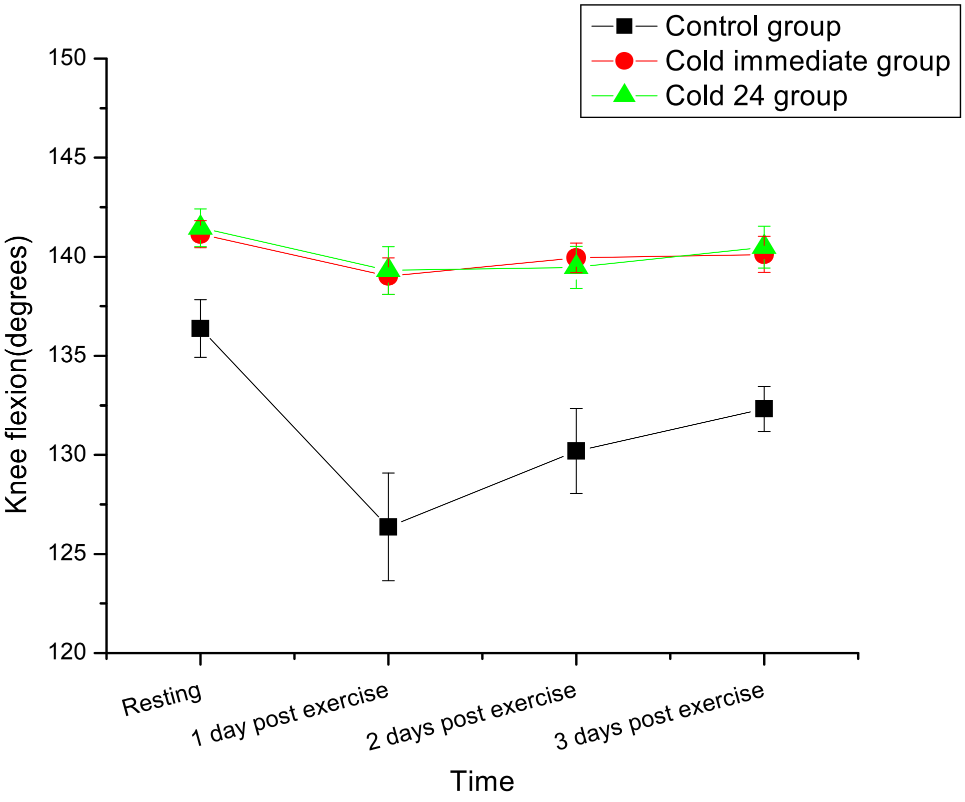

Fig. 3. The point during passive movement of the knee where pain was felt in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

3.4 Skin Current

Skin current for the average of the 18 sites above the quadriceps muscles is shown in Fig. 4. There were minor differences in the resting micro current from one subject to the other, perhaps due to differences in subcutaneous fat thicknesses. Therefore, the current was expressed as a percent of the first day's current as shown in this figure. After the first day, the skin currents were significantly lower in all 3 groups of subjects (P<.01). For the control group, skin current continues to drop for the next 2 days and was significantly lower each day (P<.01). But for the other 2 cold groups, current was not significantly less than the resting data on days 2 and 3.

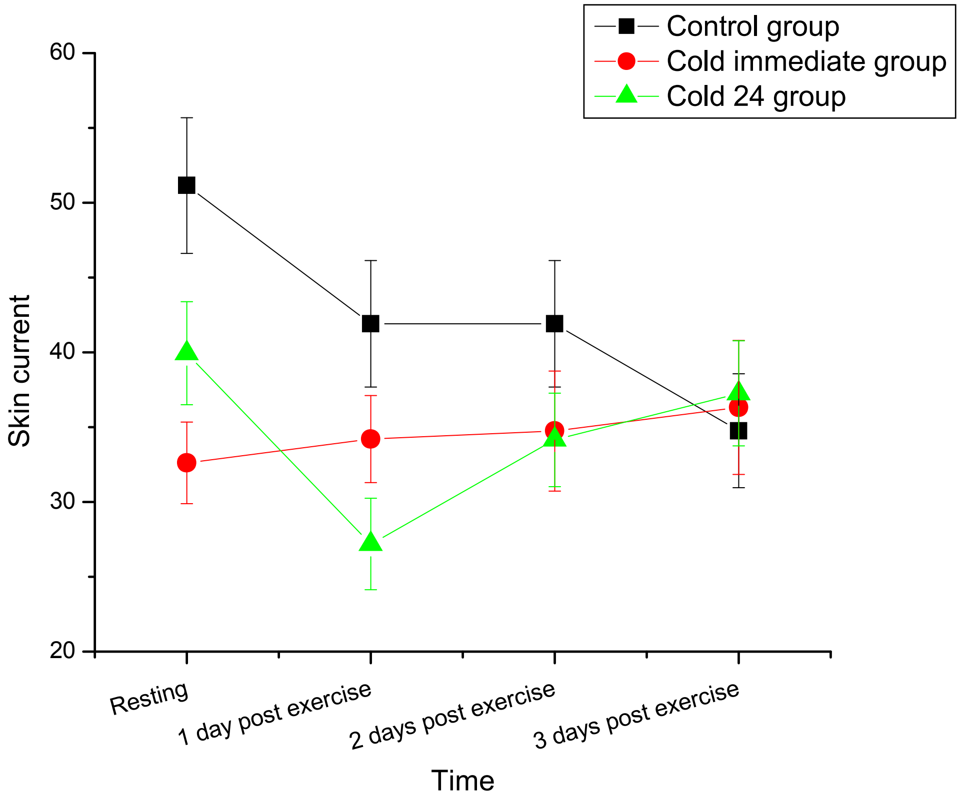

Fig. 4. The average skin current over the belly of the quadriceps muscles in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

3.5 Force to Passively Move the Leg

The force needed to flex the knee was measured from the knee at 90 to 125 degrees. Fig. 5 shows the force measured at 110 degrees of flexion. This measuring point was used since the measurement was well after the start of movement (90 degrees) and when the inertia of the leg was brought into motion and when motion was at steady state. At this point, there were some differences in the forces to move the leg depending on the leg length and girth of the leg from one individual to the next. Therefore, in this figure, all of the data was normalized in terms of the force to flex the knee before the exercise in each subject. There was no difference in the force to flex the leg one day after the exercise bout. In the group that had cold immediately after the exercise, force stayed constant over the next 2 days. For the group that had no cold applied, force to move the leg increased significantly in the 2nd and third day (*P*<.01). For the group that had cold applied 24 hours after the exercise or cold immediately, there was no significant change in force at days 1, 2 and 3 days post exercise.

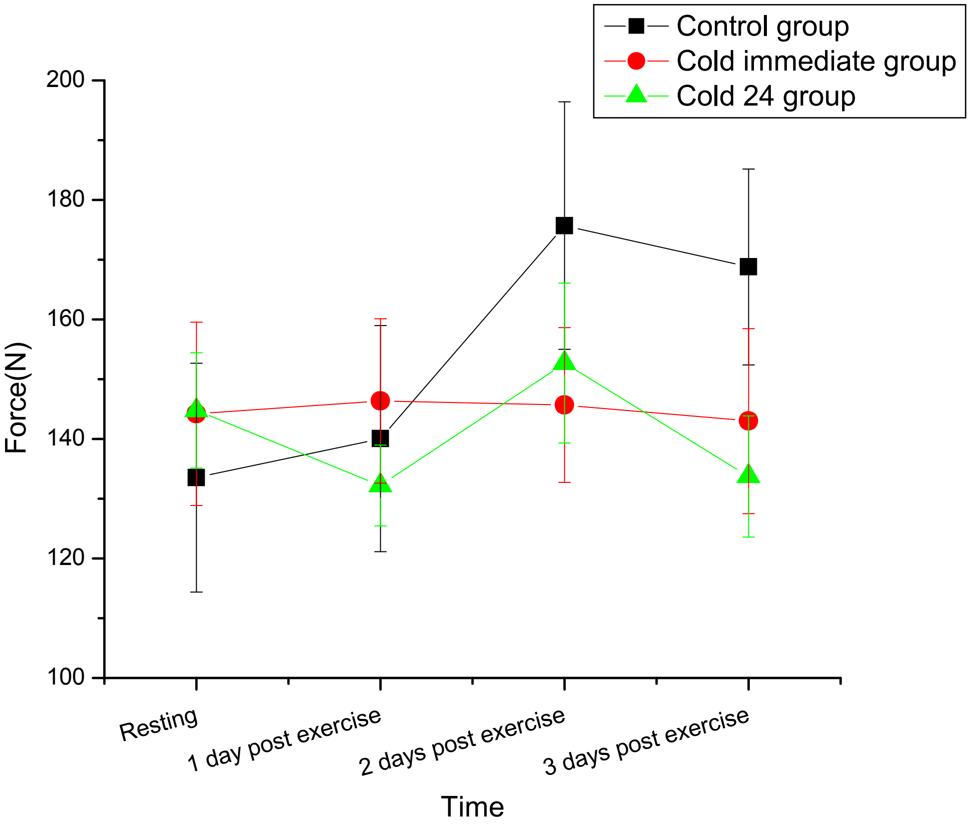

Fig. 5. The force required to passively move the quadriceps muscle with the knee at 110 degrees in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

Fig. 6 shows the hysteresis curve for the same measurement. The force to flex the knee at the 110 degree point and to allow it to extend to the 110 degree point is different. This difference is called the hysteresis. As shown in Fig. 6, for the 2 groups that received cold, the hysteresis stayed constant over the 4 day period. But for the control group, there was an increase in the difference between the force of flexion and extension that peaked on the 2nd day post exercise and was still significantly higher than rest at the last day of measurements ($P<.01$).

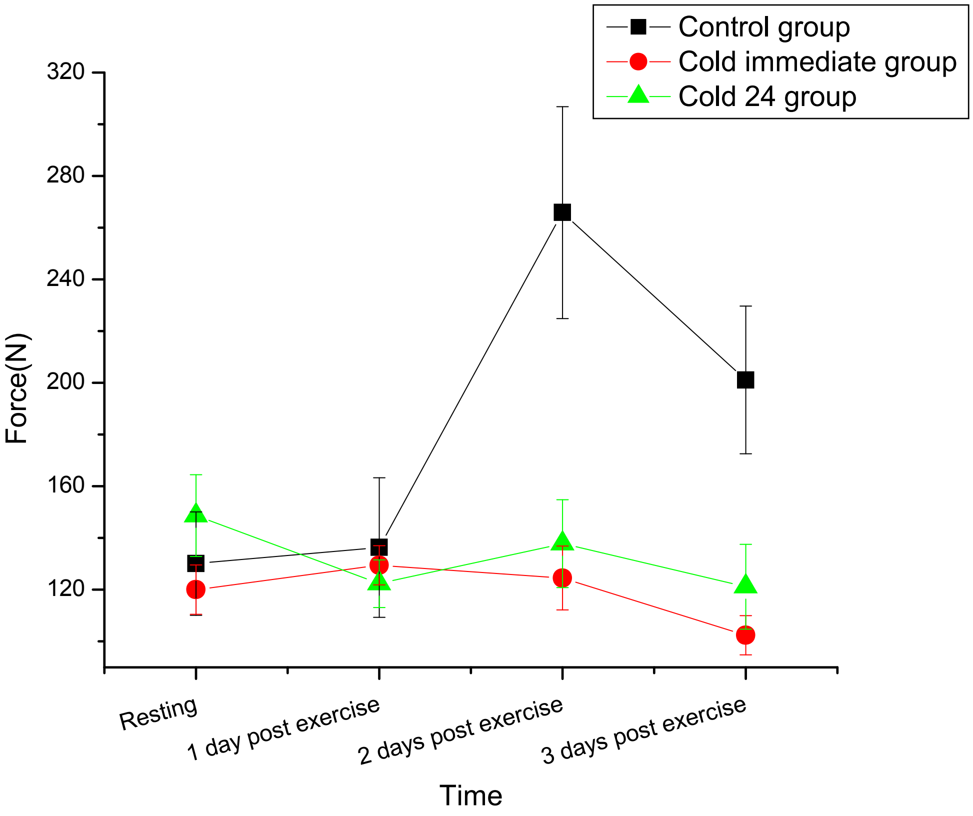

Fig. 6. The force required to passively move the quadriceps muscle with the knee at 110 degrees during flexion minus extension force in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

3.6 Knee Ligament Laxness

The movement of the tibia was measured at 3 levels of force. The results for the highest force are shown in Fig. 7. There were no significant differences between the 3 groups on any measuring day. For all groups, there was less displacement of the tibia with the highest force applied on the KT2000 by the second day post exercise. The reduction in displacement of the tibia was significant (*P*<.01) at day 1 and 2 compared to the resting data.

3.7 Discussion

Cold has been used in Physical Therapy for thousands of years [25]. The premise has always been that cold reduces both pain and swelling in over exercised tissue [26,27]. Certainly, there is ample data that cooling has physiological effects. The cold receptors in the body that operate in the non-painful physiological temperature range are specialized ion channels called trpm8 (melastatin) channels [28,29]. When cooled, the TRpm8 receptor increases calcium permeability in sensory nerves [30]. They are sensitive to both cold and menthol [25,28]. Low doses of menthol produce a cooling sensation but high doses produce a burning sensation [31]. Activation of the trpm8 receptors have been shown to reduce pain sensation and reflex pain activity [25]. The reduction in pain probably occurs in the dorsal horn of the spinal cord with the release of the neurotransmitter glutamine in pain pathways [11] Glutamate is an inhibitory neurotransmitter that reduces transmission of pain from sensory afferent. Pain can be gated away by activation in the dorsal horn by these inhibitory neurotransmitters[32].

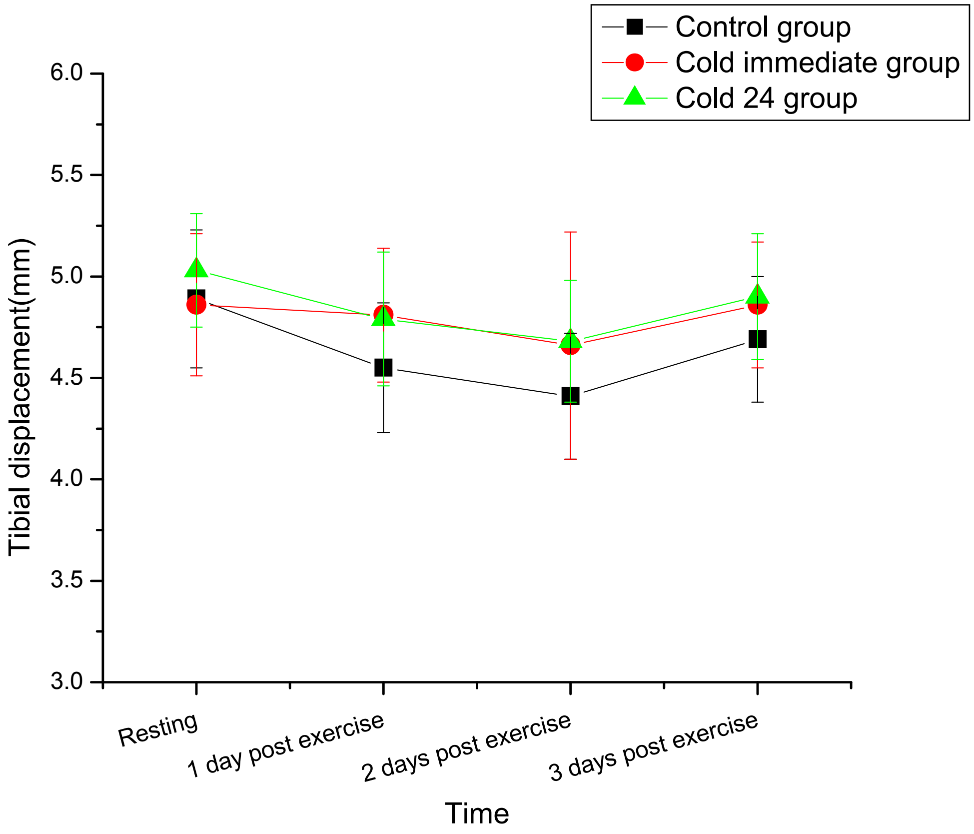

Fig. 7. The displacement of the tibia with a force of 133.2 newton applied to measure ACL laxity in the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 20 subjects +/- the standard deviation

Cold also can decrease inflammation and edema [33,34]. However, studies have questioned the ability of brief cold treatment to penetrate deep into tissue [7,35]. This becomes even more complex in that when cold is used via immersion of the limb, tissue hydrostatic pressure also increases and it is difficult to discern the effect of cold independently of pressure [7]. In these same studies, the measure of DOMS was also quite variable and largely subjective making the interpretation of the results even harder.

In the present investigation, a more comprehensive evaluation of cold was accomplished. More objective measures of the effect of cold on soreness such as muscle strength and range of motion as well as current flow through the quadriceps muscle and muscle and tendon elasticity were used as measures of damage. These measures were used to compare the effects of cold used immediately after and 24 hours later on muscle. In other studies the temperature of the cold source varied from 15 degrees centigrade to 0 degrees centigrade. Twenty minutes of exposure to an ice pack was used here since previous studies have shown that this will lower muscle temperature [36]. The results seem fairly conclusive. The analog visual pain scale showed the greatest soreness in the no ice group and the least soreness in the ice immediate group. This subjective data was paralleled by the resistive data through the quadriceps. The resistance of the tissue to the movement of electrical current has been shown to reliably indicate tissue damage. The direct current resistance of the tissue is uninfluenced by blood flow and very repeatable if electrodes are applied at constant pressure and separation distance [37]. The results here confirm less tissue damage in the cold groups compared to the control group. The force needed to move the knee through range of motion offers more support for this hypothesis. Only in the control group did force increase to passively move the leg. This showed damage to the muscle and/or its tendons making them stiff. Further, the hysteresis in the movement curve is a measure of elastic energy storage in the muscle. In the cold groups there was little change after exercise. In the control group, hysteresis increased, again showing structural damage to the muscle had occurred in the control group. This caused the muscle to be stiffer if cold wasn't used. ACL laxness was not different in any group of subjects pre and post exercise. Here there was less tibial displacement for a given force on the tibia after exercise showing swelling or damage to the ACL. The cold and control groups were not different. But since cold was not applied to the knee, it is not surprising.

There are several limitations to the study. First of all, the exercise was on all young and fairly fit individuals who were students at the university. Data may be different in older individuals. Also, it may be different with pathologies such as diabetes. It was also on a fairly small subject number and only squatting as the exercise. Other sports and other activities may yield different results.

4. CONCLUSION

From a subjective and objective standpoint, cold helped reduce damage to the quadriceps after heavy exercise. Cold immediate was the most helpful. The disparity between this and other studies may lie in the fact that data was not confused with increased tissue hydrostatic pressure which occurs when immersing the leg in cold water, causing a reduction in edema by increased tissue hydrostatic pressure. Further, cold was not just cool water but ice packs, a form of cooling capable in a short time in reducing deep tissue temperatures. Therefore, these data are encouraging in that they isolate the effect of cold from hydrostatic pressure showing good results from cold packs post exercise. For the clinician, this shows that when patients are sent home with home exercise programs, a reusable cold pack may allow greater home exercise compliance with therapist's orders by reducing tissue damage.

COMPETING INTERESTS

The authors declare no conflict of interest but this work was supported under contract WI173615.

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