JOURNAL OF SPORTS SCIENCES, 2017
http://dx.doi.org/10.1080/02640414.2017.1312492

The efficacy of cooling with phase change material for the treatment of exercise-induced muscle damage: pilot study

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ABSTRACT

Post-exercise cryotherapy treatments are typically short duration interventions. This study examined the efficacy of prolonged cooling using phase change material (PCM) on strength loss and pain after eccentric exercise. Eight adults performed 120 bilateral eccentric quadriceps contractions (90% MVC). Immediately afterwards, frozen PCM packs (15°C) were placed over the quadriceps, with room temperature PCM packs on the contralateral quadriceps. Skin temperature was recorded continually (6 h PCM application). Isometric quadriceps strength and soreness were assessed before, 24, 48, 72 and 96 h post-exercise. The protocol was repeated 5 months later, with room temperature PCM applied to both legs. There were three treatments: legs treated with 15°C PCM packs (direct cooling), legs treated with room temperature PCM packs contralateral to the 15°C PCM packs (systemic cooling), and legs tested 5 months later both treated with room temperature PCM packs (control). Skin temperature was 9°C–10°C lower with direct cooling versus systemic cooling and control ($P < 0.01$). Strength loss and soreness were less ($P < 0.05$) with direct cooling versus systemic cooling and control (strength 101%, 94%, 93%, respectively; pain 1.0, 2.3, 2.7, respectively). Six hours of PCM cooling was well tolerated and reduced strength loss and pain after damaging exercise.

ARTICLE HISTORY
Accepted 20 March 2017

KEYWORDS
Recovery of function; exercise recovery; cryotherapy; muscle damage

Introduction

The deleterious effects of exercise-induced muscle damage (EIMD) following a bout of unaccustomed exercise, particularly when eccentric-based, in both recreational and elite athletes, are well documented (Armstrong, Warren, & Warren, 1991; Frieden & Lieber, 2001; Howatson & van Someren, 2008; Miles & Clarkson, 1994; Proske & Allen, 2005). The magnitude and duration of the EIMD response can depend on the exercise mode, duration and intensity of the exercise and is characterised by a reduction in strength and increased muscle soreness on the days after exercise (Miles & Clarkson, 1994). Timely recovery from these symptoms is therefore critical to maintain readiness to train and compete on subsequent sessions and days.

Cryotherapy relates to the cooling of an area to diminish the consequences associated with strenuous exercise and is an attractive strategy to combat the signs and symptoms of EIMD because it offers a quick, simple and if required whole body intervention. Cold water immersion (CWI) is perhaps the most popular cryotherapy strategy used to facilitate recovery after strenuous exercise (Wilcock, Cronin, & Hing, 2006), particularly when it results in EIMD. Cytotherapeutic interventions are purported to induce changes in blood flow and reduced muscle temperature (Bleakley & Davison, 2010; Gregson et al., 2011), subsequently reducing post-exercise inflammation (Yanagisawa et al., 2003), thereby reducing the potential for a delayed damage response. Part of the proposed mechanism of CWI is hydrostatic pressure exerting a compressive force of the muscles (Versey, Halson, & Dawson, 2013). CWI is limited by the fact that it can only be applied for a limited period of time due to contraindications from spending extended periods immersed in cold water, athlete tolerance to the intervention and logistical issues surrounding delivering such an intervention in applied scenarios.

There are vast variations in reported CWI protocols (Bleakley et al., 2012; Howatson & Van Someren, 2008; Leeder, Gissane, van Someren, Gregson, & Howatson, 2012). Although no consensus exists for optimal treatment criteria, the average treatment duration across studies was 12.5 ± 5.6 min with a commonly used temperature range of between 10°C and 15°C (Bleakley et al., 2012). Two systematic reviews with meta-analysis (Bleakley et al., 2012; Leeder et al., 2012) showed that CWI had a moderate effect on pain, and no effect on strength, with some benefit for power restoration. Additionally, Versey et al. (2013) subjectively reviewed 53 studies and reported that CWI appears likely to assist recovery of exercise performance more than thermoneutral or hot water immersion.

Phase change material (PCM) was patented in 1987 to improve the thermal performance of textile fibres in astronauts. When frozen PCM is heated, for example, by exposure to the human body, it will continuously absorb heat and change from solid to liquid. While the PCM melts, the temperature is held constant at the melting point until all material changes into liquid. Thus, it can maintain a low temperature for a long time.

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To date, the application of PCM has only been studied for reducing heat stress in occupational and athletic settings. Several studies have examined the relationship between recovery from heat strain during physical activity and the temperature regulating effect of PCM (Chou, Tochihara, & Kim, 2008; Gao, Kuklane, & Holmer, 2011; Reinertsen et al., 2008). When applied to exercise paradigms, some have reported a reduction in core (Barwood, Davey, House, & Tipton, 2009; Tate, Forster, & Mainwaring, 2008) and in skin temperature (Brade, Dawson, Wallman, & Polglaze, 2010; Purvis & Cable, 2000) when compared to a control.

Rapid and convenient deployment of a strategy to facilitate exercise recovery is important, particularly in scenarios when interventions like CWI are logistically challenging to implement. Based on limitations with other modalities, wearing a garment fitted with PCM might provide an eloquent solution to applying cryotherapy following strenuous exercise and could prove to be more effective (because of the extended time it can be applied for), less time consuming (entire teams could be treated simultaneously and immediately post-exercise) and logistically simpler to carry out (reusable) than other cryotherapy modalities. As a first step to understanding the potential of such an intervention, this investigation explored the novel, untested application of PCM cooling by direct application to a muscle group after damaging exercise. In this study, we applied single treatments of PCM with a phase point of 15°C, which takes approximately 3 h to equilibrate to skin temperature ~33°C. Conceptually, the recovery process could be enhanced given the cold application time is far longer than conventional cryotherapy methods, like CWI, allowing for cooler skin temperatures to be maintained for a longer period. Consequently, the purpose of this pilot study was to establish the efficacy of a novel cooling strategy (PCM) as a recovery intervention following a damaging bout of eccentric exercise. It is hypothesised that prolonged PCM cooling would alleviate strength loss and pain on the days following the eccentric exercise.

Methods

Participants

Six males and two females (mean ± SD; age, 37 ± 12 years; height, 177.1 ± 9.3 cm; body mass, 76.4 ± 9.7 kg) volunteered to participate in this study. Prior to participation, volunteers were informed of the procedures and provided written, informed consent. All participants were free from injury within the past 6 months, recreationally active and partook in regular exercise. Participants were instructed to refrain from taking non-steroidal anti-inflammatory drugs and nutritional supplements, pharmacological interventions and strenuous exercise for the duration of the two study periods. The institutional research ethics committee, in line with the Declaration of Helsinki, approved all procedures.

Experimental design

Participants were randomised in a counterbalanced order to initiate exercise on either the dominant or non-dominant leg. Participants had their strength and soreness assessed on both limbs, and then performed a damaging eccentric exercise

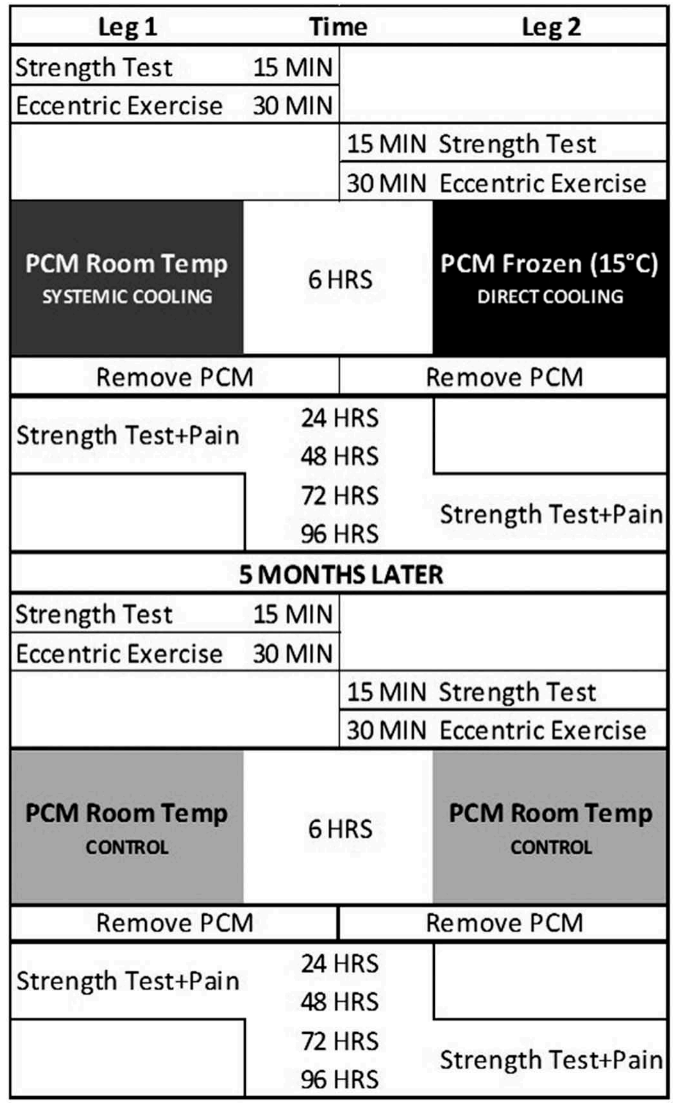

Figure 1. Schematic representation of the experimental protocol showing the sequence of events on both legs tested from baseline strength measures, to eccentric exercise, to frozen PCM application on one leg (direct cooling) and room temperature PCM on the contralateral leg (systemic cooling), to strength and pain assessments for 4 days after eccentric exercise. This was followed by a 5-month break to remove the effect of the repeated bout effect. The experimental protocol was then repeated with room temperature PCM applied to both legs after eccentric exercise (control).

protocol on the knee extensors. This was followed by the application of 15°C and room temperature PCM, with the frozen (15°C) PCM being applied to the limb that was damaged second. Preliminary testing in the lab established that the temperature gradient between the surface of the thigh and 15°C PCM result in a phase change duration of 3 h. This prompted the 15°C PCM to be changed after the initial 3 h. The protocol was repeated 5 months later, with room temperature PCM applied to both legs (Figure 1).

Experimental procedures

Participants reported to the laboratory for a total of four consecutive days (up to 96 h post-damaging exercise) after the damaging exercise to reassess quadriceps strength and muscle soreness. A limitation in using the contralateral leg as a control when damaging both legs at the same time was that cooling one leg might have a systemic effect and thus might affect the damage response in the contralateral leg. Therefore, the same participants returned to the laboratory 5 months later and the protocol was repeated bilaterally. This time room temperature PCM packs were worn on both legs for 6 h post-exercise. The 5-month delay was used to ensure that the repeated bout effect did not impact the damage response (Nosaka, Newton, & Sacco, 2005). Thus, there were three treatments: legs treated with 15°C PCM packs (defined as direct cooling), legs treated with room temperature PCM packs contralateral to the 15°C PCM packs (defined as systemic cooling), and legs tested 5 months later and both treated with room temperature PCM packs (defined as control). Strength and soreness values for the control treatment was averaged across legs. Strength testing consisted of two isometric maximum voluntary contractions (MVCs) of the knee extensors at each of 30°, 50° and 70° knee flexion on an isokinetic dynamometer (Biodex System 2, Shirley, NY, USA). The average of the two efforts at each joint angle was used for data analysis. Quadriceps pain was assessed by having participants perform a two-legged squat to 90° knee flexion and report the discomfort level for each leg using a 0- to 10-point scale (0 = no discomfort, 10 = too painful to squat to 90°). Muscle strength and soreness data were collected before, 24, 48, 72 and 96 h post-exercise. The damaging exercise protocol consisted of 120 eccentric quadriceps contractions (12 sets, 10 repetitions, 30-s rest between sets) at 90% MVC on an isokinetic dynamometer. Contractions were performed at 1.05 rad s^{-1} (60° s^{-1}) with the range of motion 5° (0° = full extension) to 95° knee flexion. Participants were seated with the trunk at approximately 90° of flexion. The protocol was then repeated on the contralateral leg. Based on a previous work (McHugh & Pasiakos, 2004; McHugh & Tetro, 2003), it was expected that an angular velocity of 1.05 rad s^{-1} was sufficiently slow enough to allow participants to accurately produce the target torque and would result in significant strength loss and pain on subsequent days.

Phase change material application

Immediately after the second leg was tested, Glacier Tek USDA BioPreferred PureTemp PCM (Plymouth, MN, USA) "frozen" at 15°C was placed inside compression shorts over the quadriceps of the second leg, and PCM at room temperature (~25°C) was applied to the first leg tested. Participants were allowed to leave the lab following testing and the application of the PCM, but were instructed to change the 15°C PCM pack following 3 h to a fresh "frozen" 15°C PCM pack; all shorts and packs were removed after a total of 6 h. Before application of PCM, a thermistor probe programmed to acquire data at 1-min intervals was taped directly to the surface of the skin over each of the thighs at approximately mid-femoral length (OMEGA Engineering, INC., Stamford, CT, USA). Quadriceps skin temperature was recorded continually for the 6 h of wear.

On return to the laboratory 5 months later, the protocol was repeated bilaterally; however, room temperature PCM packs were worn on both legs for 6 h after damaging exercise. Consequently, there were three treatments: legs treated with 15°C PCM packs (defined as direct cooling), legs treated with room temperature PCM packs contralateral to the 15°C PCM packs (defined as systemic cooling), and legs tested 5 months later and both treated with room temperature PCM packs (defined as control). Strength, pain and skin temperature values for the control treatment were averaged across legs.

Statistical analysis

Strength at each of the three test angles was expressed as a percentage of pre-exercise strength to remove the effect of inter-individual variation in knee extension strength. Strength prior to the initial eccentric exercise bout was compared to strength prior to the eccentric exercise performed 5 months later to ensure there was no systematic change over time that might have affected susceptibility to EIMD. The effect of PCM cooling on strength loss on the days after eccentric exercise was assessed using $3 \times 3 \times 4$ treatment by angle by time repeated measures analyses of variance (ANOVA). The three levels for the treatment factor were direct cooling, systemic cooling and control. The three levels for the angle factor were 30°, 50° and 70° knee flexion. The four levels for the time factor were 24, 48, 72 and 96 h after the eccentric exercise. The effect of PCM cooling on pain on the days after eccentric exercise was assessed using 3×4 treatment by time repeated measures ANOVA. Since it is possible that cooling one leg might have affected the damage response in the contralateral leg it was hypothesised that the magnitude of strength loss and pain for the systemic cooling treatment would lie between the responses for the direct cooling and control treatments. Therefore, the linear contrast for the treatment effects are reported in addition to the main treatment effect as recommended by Atkinson (2002). Normality of all data sets was examined using the Shapiro–Wilk test. Additionally, where assumptions of sphericity were violated, Greenhouse–Geisser corrections were applied to tests of within participant effects.

The average skin temperature during the 6-h PCM treatment was compared between treatments using a repeated measures ANOVA. Pairwise comparisons of temperature, pain and strength loss between the three treatments were performed using Fisher's least significant difference test. Statistical analyses were performed using SPSS v.21 (IBM, Armonk, NY, USA). Mean ± SD are reported in the "Results" section and the tables. Mean ± SE are reported in the figures. A P-value of less than 0.05 was considered statistically significant.

Results

Temperature

There was a treatment effect for skin temperature (direct cooling < systemic cooling and control, $P < 0.001$; Table 1). Direct cooling resulted in an average skin temperature of 21.9 ± 1.0°C for the 6-h treatment compared with 31.7 ± 1.4°C for systemic cooling and 31.3 ± 1.3°C for control (effect size = 5.96 for direct cooling versus other two treatments).

Table 1. Six-hour average temperature (°C) and temperature at hour 6 post-exercise intervention.

	6 h avg (°C)	Temp at 6 h (°C)
Direct cooling	21.9 ± 1.0	21.7 ± 0.7
Systemic cooling	31.7 ± 1.4	31.2 ± 1.4
Control	31.3 ± 1.3	31.3 ± 1.8

These data show no drift in temperature over the 6-h cooling period.

Strength

Baseline knee extension strength on the direct cooling leg (220 ± 61 N · m) was well reproduced 5 months later (219 ± 54 N · m; mean difference 1 ± 19 N · m; ICC = 0.947 [95% CI 0.760–0.989]). Similarly, knee extension strength on the systemic cooling leg (229 ± 60 N · m) was well reproduced 5 months later (229 ± 49 N · m; mean difference 0 ± 22 N · m; ICC = 0.917 [95% CI 0.643–0.983]). At baseline peak knee extension strength occurred at 70° (281 ± 24 N · m) with lower torques at 50° (230 ± 20 N · m, $P < 0.001$) and 30° (162 ± 15 N · m, $P < 0.001$). Strength loss after eccentric exercise was normally distributed. There was a trend for a significant main effect of treatment on strength loss ($P = 0.097$). The treatment effect was not different between test angles (treatment by angle, $P = 0.54$). Additionally, strength loss (averaged across all treatments) was not different between test angles (main effect of angle, $P = 0.26$). The treatment effect was significant at 30° and 50°, but not at 70° (Table 2). The treatment by angle by time interaction was not significant ($P = 0.580$).

As hypothesised, the treatment effect on strength loss showed a significant linear trend ($P = 0.022$; partial $\eta^2 = 0.529$; Figure 2). Average strength expressed as a percent of baseline for the 4 days following the exercise intervention was 101 ± 7% for direct cooling, 94 ± 14% for systemic cooling ($P = 0.086$ vs. direct cooling; effect size = 0.67, 95% CI −0.37 to 1.63), and 93 ± 7% for control ($P = 0.022$ vs. direct cooling; effect size = 1.14, 95% CI 0.03–2.12). Peak strength loss occurred 1 day following the exercise intervention (direct cooling 93 ± 13%, systemic cooling 89 ± 16%, control 85 ± 10%; direct cooling vs. control, $P = 0.03$, direct cooling vs. systemic cooling, $P = 0.13$). Strength recovered over the 4 days after eccentric exercise ($P = 0.002$). By day 4, strength

Table 2. Strength as a percentage of baseline strength for each test angle, on each post-exercise day for each treatment.

Isometric strength on the days post eccentric exercise (% baseline)					
Knee angle	Treatment	Day 1	Day 2	Day 3	Day 4
	Direct cooling	98 ± 8	106 ± 12	105 ± 6	106 ± 11
30°	Systemic cooling	94 ± 14	93 ± 16	94 ± 15	96 ± 14
	Control	87 ± 9	95 ± 7	93 ± 7	96 ± 7
Linear treatment effect		$P = 0.002$			
Treatment by time effect		$P = 0.557$			
	Direct cooling	94 ± 12	102 ± 8	106 ± 8	104 ± 8
50°	Systemic cooling	89 ± 19	93 ± 20	96 ± 18	93 ± 15
	Control	85 ± 11	94 ± 11	97 ± 10	99 ± 11
Linear treatment effect		$P = 0.034$			
Treatment by time effect		$P = 0.356$			
	Direct cooling	89 ± 17	99 ± 11	102 ± 8	101 ± 11
70°	Systemic cooling	84 ± 16	96 ± 19	97 ± 18	97 ± 15
	Control	82 ± 11	91 ± 9	95 ± 12	98 ± 15
Linear treatment effect		$P = 0.209$			
Treatment by time effect		$P = 0.891$			
Overall linear treatment effect			$P = 0.022$		
Treatment by time effect			$P = 0.651$		
Treatment by angle by time effect			$P = 0.580$		

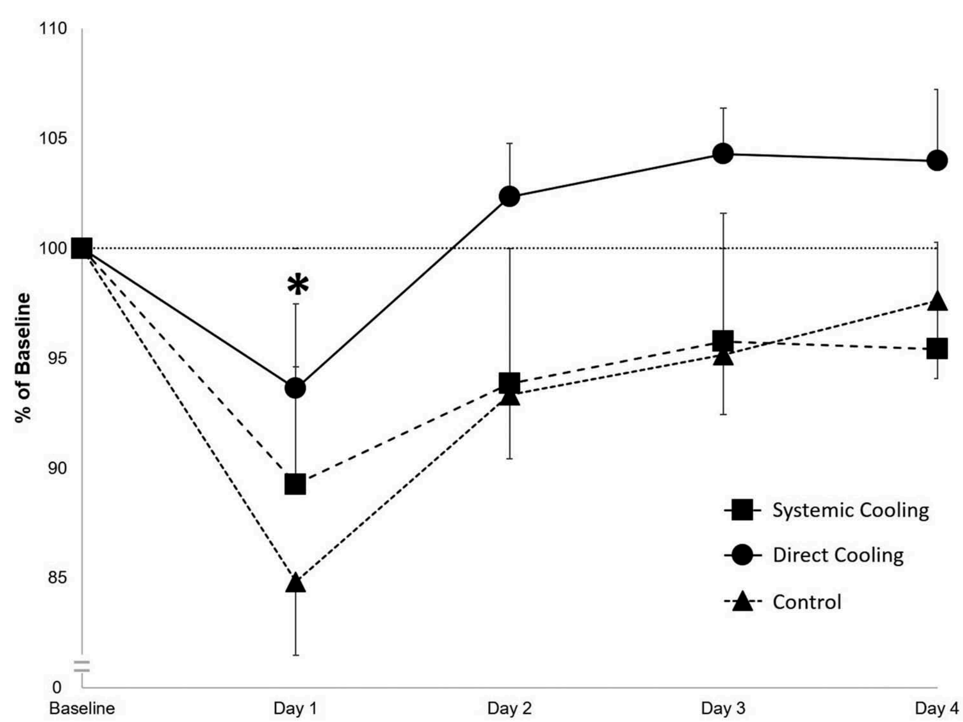

Figure 2. Isometric strength loss (averaged across all three test angles) after the bout of eccentric exercise in direct cooling, systemic cooling and control conditions. Strength values are percent of isometric strength immediately before the eccentric bout (baseline strength). Treatment effect $P = 0.097$, time effect $P = 0.017$, treatment by time $P = 0.536$, treatment effect linear trend $P = 0.022$.
*Strength loss was significantly greater in the control group than the group treated with direct cooling on day 1 (direct cooling vs. control, $P = 0.03$).

was 103 ± 8% for direct cooling, 95 ± 14% for systemic cooling and 98 ± 10% for control.

Average torque during the eccentric exercise was not different between direct cooling (241 ± 53 N · m), systemic cooling (240 ± 52 N · m) and control (251 ± 41 N · m; $P = 0.165$; ICC = 0.900 [95% CI 0.708–0.977]).

Pain

Pain after eccentric exercise was normally distributed. There was a trend for a significant main effect of treatment on pain ($P = 0.071$). As hypothesised, the treatment effect showed a significant linear trend ($P = 0.029$; partial $\eta^2 = 0.518$; Figure 3). Average pain for the 4 days following the exercise intervention was 1.0 ± 1.2 for direct cooling, 1.7 ± 1.6 for systemic cooling ($P = 0.116$ vs. Direct cooling; effect size = 0.45) and 2.3 ± 0.7 for control ($P = 0.029$ vs. direct cooling; effect size = 1.33). Pain resolved over the 4 days after eccentric exercise ($P < 0.001$). By 4 days after the eccentric exercise, pain had mostly resolved (0 ± 0 for direct cooling, 0.4 ± 0.7 for systemic cooling and 0.8 ± 0.9 for control).

Discussion

The purpose of this study was to test the potential efficacy of PCM cooling in improving recovery from EIMD. The results indicate that prolonged PCM cooling mitigated strength loss and pain on the days following the eccentric exercise. Given the small sample size, it was not possible to examine whether direct cooling to one leg had a beneficial effect on recovery in the contralateral leg (systemic cooling) but the treatment effect on strength and pain indicates that this was a possibility. Overall, the findings that strength over the 4 days after eccentric exercise average 101% of baseline, and pain averaged 1.0 on a 10-point scale indicate that minimal muscle damage occurred after PCM cooling. For the contralateral leg (systemic cooling) and control treatment (5 months later), the corresponding strength and pain values were 94% and 93% for strength and 1.7 and 2.3 for pain, respectively.

Child, Saxton, and Donnelly (1998) demonstrated greater strength loss at short muscle lengths (20° compared with 100°) after 75 maximal eccentric contractions of the knee extensors. Therefore, strength measures were made at three different angles in the present study. Since peak knee extension torque occurs at around 70°, with lower values at 50° and 30°, strength values from solely 70° might underestimate the damage effect at shorter muscle lengths. Additionally, the protocol used in this study utilised similar range of motion to that used by McHugh and Tetro (2003). In that study, strength loss was less at 110° than at other angles. In the present study, strength loss was not different between 70°, 50° and 30°. Strength measures at angles less than 30° or greater than 100° may be needed to see a clear effect of muscle length on strength loss after eccentric exercise. Of relevance to the present study, the effect of PCM cooling on strength loss was not different between test angles ($P = 0.54$).

As a pilot study, the primary purpose was to demonstrate potential efficacy of PCM cooling in recovery from damaging exercise to establish a proof of concept for future studies. Future work will need to establish the efficacy of PCM cooling in a larger sample of participants, with a between groups design to negate the potential confounding effect of a systemic effect. Additionally, future work needs to examine potential mechanisms of PCM cooling such as an anti-

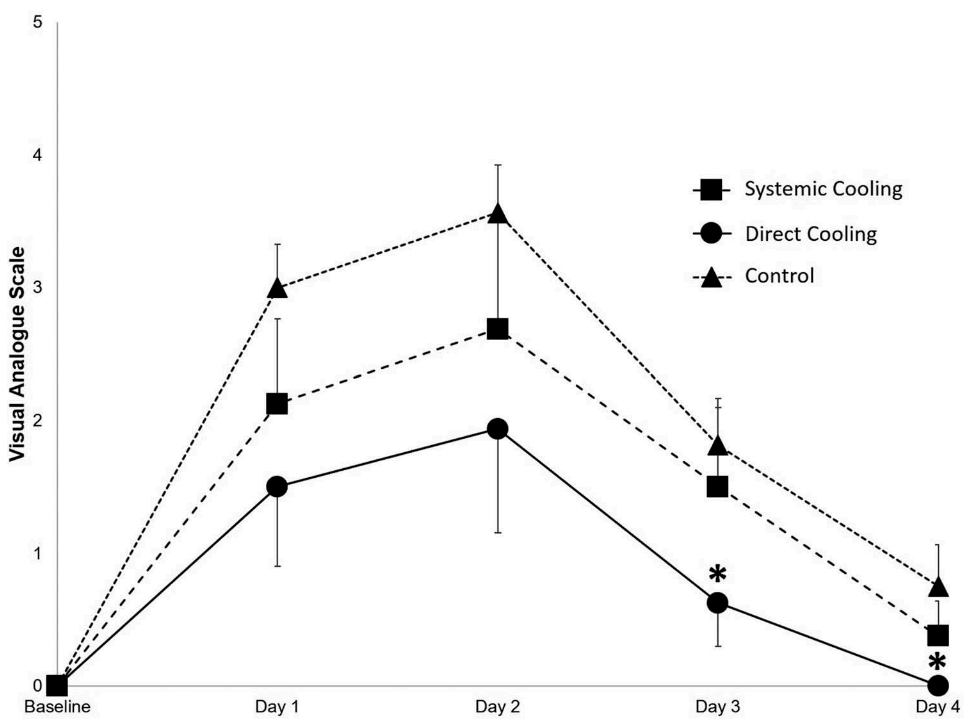

Figure 3. Subjective reports of pain on a 0–10 scale (0 = no discomfort, 10 = too painful to squat to 90°) in direct cooling, systemic cooling and control conditions. Treatment effect $P = 0.071$, time effect $P = 0.001$, treatment by time $P = 0.740$, treatment effect linear trend $P = 0.029$.
*Direct cooling < control ($P < 0.05$).

inflammatory effect. However, it is important to understand the mechanism of EIMD and how PCM cooling might mediate such a process. The intended purpose of the prolonged period of PCM cooling used in this study was to intervene during this period of injury proliferation. The application of 15°C PCM packs to the quadriceps for a duration of 6 h reduced skin temperature to 22°C, and this reduction was maintained for the duration of the treatment. The return of skin temperature after the removal of the PCM packs was not recorded. By comparison, CWI at 10°C for 20 min post-exercise reduced skin temperature to 22°C immediately after the CWI, with return to baseline skin temperature within 1 h (Minett et al., 2014). The potential benefits of CWI or PCM cooling in accelerating recovery after EIMD are possibly due to reduced blood flow limiting the post-exercise proliferation of muscle damage. Additionally, reduced muscle temperature might reduce the inflammatory response. Since the intramuscular inflammatory response initiates 2–6 h post-exercise (Armstrong et al., 1991), a prolonged cooling intervention during this time frame has potential.

Of the 17 studies included in the systematic review by Bleakley et al. (2012), the average water temperature was 11 ± 4°C (range 5–15°C) and the average duration was 11.5 ± 7.4 min (range 3–30 min). All 17 studies used CWI immediately or within 20 min of the end of exercise and 7 studies provided treatments on subsequent days. The longest total treatment was two 15 min immersions in 15°C separated by 10 min and performed immediately post-exercise, and repeated 4, 8 and 24 h post-exercise, for a total treatment duration of 120 min (Skurvydas et al., 2006). Of note, this study showed a beneficial effect of CWI versus control for both pain and strength recovery on the days after performing 100 drop jumps. In the present study, a 6-h single 15°C PCM cooling treatment was provided immediately post-eccentric quadriceps exercise and showed beneficial effects on pain and strength versus control on subsequent days. Together, these studies point to the need for increased cryotherapy dose to improve effectiveness. The practicality of delivering repeated CWI treatments in the 24 h after exercise can be challenging. By contrast, wearing a pair of shorts fitted with 15°C PCM packs may be a practical alternative to providing prolonged cooling to muscles post exercise.

While the present study sets the stage for larger studies on the potential benefit of PCM cooling, it is important to note the inherent limitations in this work. A sample of eight participants was sufficient to indicate a potential benefit but the sample size was relatively small. However, the effect sizes for the differences in strength and pain between the direct cooling and control treatments were moderate for pain (0.45) and large for strength (0.76) and add to the positive interpretation of the potential benefit of PCM cooling. Additionally, since both males and females were included, the group was not fully homogenous. The use of the contralateral leg as a control condition for the initial eccentric bout of exercise overlooked the possibility that cooling one leg might affect subsequent damage in the contralateral leg (systemic cooling). This necessitated the use of a control treatment 5 months later. Symptoms of EIMD have been shown to be very consistent within participants when a damage protocol is repeated a few months later (Nosaka et al., 2005), so the use of the control treatment was not a limitation. However, the sample size was insufficient to determine if indeed there was a systemic effect as there was insufficient power to detect a difference between control and systemic treatments.

As mentioned previously, the mechanism by which PCM might be providing a benefit was not examined. In this regard, it would be helpful to measure the intramuscular and core temperature changes in response to PCM cooling. Moreover, a recent meta-analysis indicated that compression garments worn for recovery purposes can facilitate the return of strength and power (Hill, Howatson, van Someren, Leeder, & Pedlar, 2013). Since this study has indicated potential efficacy, the lack of measurement of compression in this study is a confounding factor. Although the same shorts fitted with PCM packs were worn on both test occasions, in the initial session, the direct cooling condition required the PCM to be frozen while the systemic cooling condition required the PCM to be melted. This difference may have affected the compression on the thigh. Future research should utilise a pressure monitoring device to measure the degree of pressure exerted by the garments.

An additional confounding factor is the fact that the systemic cooling leg did not receive the room temperature PCM application until the direct cooling leg completed the eccentric exercise. Thus, the direct cooling leg received compression immediately after the eccentric exercise while the systemic cooling leg received compression approximately 30–40 min after the eccentric exercise. The possibility that this delay in application of compression affected subsequent symptoms was assessed by comparing strength loss and pain between legs after the control session, when room temperature PCM packs were applied to both thighs. In the control session, the application of compression shorts was also delayed by 30–40 min in one leg compared with the contralateral side. However, there was no difference in pain ($P = 0.227$) or strength loss ($P = 0.787$) between legs on the days after the damaging exercise in the control condition. Therefore, the delay in application of compression caused by the study design was not a confounding factor.

This study demonstrated PCM cooling to be effective in a single muscle group EIMD model. Therefore, this research cannot be directly applied to a training environment where multiple muscle groups are stressed and the optimal application of cooling to maximise recovery of lower extremity function is not known. The present results indicate that local PCM application can be indicated to accelerate muscle damage in a single muscle group EIMD model, and that 6 h of direct frozen state PCM cooling is well tolerated and results in significant recovery of pain and strength indices. Additionally, this was the first study to demonstrate that prolonged PCM cooling is a very practical and portable cryotherapy method compared to other cooling modalities (i.e., CWI). These results support the need for a larger study to address the effect of PCM cooling on additional markers of EIMD in a larger sample, with a between participant's design using a passive recovery control group. Such work will need to examine potential mechanisms by which PCM cooling might work, such as reduced inflammation.

Conclusion

This is the first examination of the application of PCM as a recovery modality for the symptoms of EIMD. These data suggest that PCM cooling accelerates the recovery of muscle function after EIMD and reduces the pain associated with muscle damage. Given this evidence and the practical utility of a wearable garment to deliver prolonged cooling to muscles after damaging exercise, further investigation of PCM cooling in muscle recovery is warranted.

Acknowledgement

The novel application of PCM in exercise-induced injury and recovery was conceptualized and implemented by the author Dr Malachy McHugh.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

There has been no financial assistance for the project.

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