Northumbria Research Link

Accelerated muscle recovery in baseball pitchers using phase change material cooling

Michael J Mullaney [1,2]
Malachy P McHugh [1,4]
Susan Y Kwiecien [1,4]
Neil Ioviero [3]
Andrew Fink [2]
Glyn Howatson [4,5]

[1] Nicholas Institute of Sports Medicine & Athletic Trauma, Lenox Hill Hospital
[2] Mullaney & Associates Physical Therapy
[3] Kean University
[4] Department of Sport, Exercise and Rehabilitation, Northumbria University
[5] Water Research Group, North West University, Potchefstroom, South Africa

Corresponding Author:
Malachy P. McHugh PhD
Nicholas Institute of Sports Medicine & Athletic Trauma
MEETH a division of Lenox Hill Hospital
210 East 64th St.
New York, New York 10065
212-434-2714
212-434-2687 fax
mchugh@nismat.org

ABSTRACT

Purpose: The purpose of this study was to document recovery following a pitching performance and determine if prolonged post-game phase change material (PCM) cooling of the shoulder and forearm accelerates recovery. **Methods:** Strength, soreness and serum creatine kinase (CK) activity were assessed prior to, and on the two days following pitching performances in 16 college pitchers. Pitchers were randomized to receive either post-game PCM cooling packs on the shoulder and forearm, or no cooling (control). PCM packs were applied inside compression shirts and delivered cooling at a constant temperature of 15°C for 3 hours. Strength was assessed for shoulder internal rotation (IR), external rotation (ER), empty can test (EC) and grip. **Results:** Total pitch count was 60±16 for 23 PCM cooling games and 62±17 for 24 control games (P=.679). On the days following pitching IR strength (P=.006) and grip strength (P=.036) were higher in the PCM cooling group versus control. One day after pitching IR strength was 95±14% of baseline with PCM cooling versus 83±13% for control (P=.008, effect size *d* 0.91) and 107±9% versus 95±10% for grip strength (P=.022, effect size *d* 1.29). There was a trend for greater ER strength with PCM cooling (P=.091, effect size *d* 0.51). The EC strength was not impaired after pitching (P=.147) and was therefore unaffected by PCM cooling (P=.168). Elevations in soreness and CK were not different between treatments (Treatment by Time CK P=.139, shoulder soreness P=.885, forearm soreness P=.206). **Conclusion:** This is one of the first studies to document impairments in muscle function on the days following baseball pitching, and the first study showing a novel cryotherapy intervention that accelerates recovery of muscle function in baseball pitchers following a game.

Key Terms: Cryotherapy, hand-held dynamometer, creatine kinase, soreness

Introduction

Considering the significance of pitching to success in baseball, and the importance placed on the number of days between starts, it is surprising that there is a dearth of research on recovery in pitchers. The research on recovery on the days after a pitching performance is limited to a few studies with small samples (6-10 subjects)(1,2,3,4,5). Three of the five studies examined soreness (2,3,5), two studies examined blood markers of muscle damage and/or inflammation (2,5), two examined MRI indices of muscle swelling (1,3), and only one study examined strength (4). Since strength measures provide a better quantification of exercise-induced muscle damage than blood markers or soreness indices (6), it is surprising that there are not more studies documenting strength recovery after pitching. There is even less research on recovery strategies for baseball pitchers which is surprising, considering the marked strength loss evident immediately after a pitching bout (7). Yanagisawa et al compared the effects of post-game icing, versus light exercise, versus the combination of icing plus light exercise, on strength and soreness one day after seven pitchers threw 98 pitches on three separate occasions (4). Light exercise and the combination of ice and light exercise provided some apparent benefit, but ice alone did not. However, the sample size was insufficient to make meaningful conclusions on the potential benefits of the recovery interventions. There are a few studies in the literature examining the effects of cryotherapy on indices of recovery between innings in baseball pitchers targeted at maintaining performance (8,9,10). Ice applied to both the shoulder and elbow between innings has been shown to attenuate the decrease in pitching velocity, increase velocity without jeopardizing accuracy, increase the overall amount of work done (22% more pitches), as well as decrease ratings of perceived exertion and facilitate subjective recovery (8,9). These results are of limited relevance to the present work given that an intervention intended to repress fatigue during a game is not immediately relevant to recovery on the subsequent days.

Despite the fact that post-game icing of the shoulder and elbow has been in common practice for years there is no good supporting science specific to its application for recovery in baseball pitchers. Research on cold water immersion provides some indirect evidence in support of post-game icing in baseball. For example, repeated cold water immersions of the upper arm after eccentric exercise of the elbow flexors accelerated recovery of motion and reduced creatine kinase (CK) levels, a blood marker of damage (11). Additionally, in an animal model prolonged direct cooling to muscle following a closed soft tissue injury reduced proliferation of the injury (12). By contrast, intermittent topical cooling over a 72-hour period delayed recovery following bouts of eccentric exercise and in an animal model of muscle crush injuries icing impaired tissue repair (13,14).

The goal of post-exercise cryotherapy interventions is to reduce the proliferation of tissue disruption. Repeated post-exercise ice treatments may be more beneficial than a single treatment but in practice are inconvenient as the athlete must be relatively stationary during the treatment and typically needs to remain in the athletic training room for proper reapplication of ice. Recently post-exercise cooling using phase change material (PCM) cooling packs worn inside compression shorts has been shown to accelerate recovery after eccentric exercise in recreational athletes and after games in professional soccer players (15,16). The PCM packs in these studies froze at 15° C and maintained this temperature for at least three hours. These interventions provide marked reductions in intramuscular temperature and allow the athlete to leave the training room while the treatment continues (16). The fact that the packs are at 15° C means that there is little to no risk of cold-induced injury. Thus, the combination of safety and practicality make PCM cooling an attractive recovery intervention for athletes.

The purposes of this study were twofold. The first purpose was to examine the indices of recovery following baseball pitching, specifically examining strength recovery since only one prior small sample study has documented strength recovery in pitchers (4). The second purpose was to examine the effectiveness of post-game PCM cooling on indices of recovery in pitchers. Based on prior work it was hypothesized that PCM cooling would accelerate recovery of muscle function (15,16).

Methods

Participants

Sixteen male, NCAA Division III collegiate baseball pitchers (age 21.2±1.2; height 1.85±0.06 m; body mass 85±13 kg; 5 freshmen, 5 sophomores, 2 juniors, 4 seniors) volunteered to participate in this study. All participants were injury free for >6 months, cleared for full pitching participation by athletic training staff, and remained injury free for the duration of the study. Prior to participation, pitchers were informed of the procedures and provided written, informed consent. The institutional research ethics committee, in line with the Declaration of Helsinki, approved all procedures.

Experimental Design

Upper extremity strength, soreness of the shoulder and forearm, and serum CK were assessed prior to, and on each of the two days following a pitching performance. On days of data collection, data were obtained prior to any physical activity initiated by the pitchers. The order of data collection remained the same throughout the data collection period. Pitchers were randomized to receive either 1) PCM cooling packs to the shoulder or shoulder and forearm or 2) no cooling (control) after a pitching performance. Data were collected in the NCAA sanctioned fall season (September) and the NCAA sanctioned pre-season (January/February). Since the flexible microsphere filling in the PCM pack applied at the elbow was a novel material made available following the initial data collection period (fall season), they were only applied in the spring pre-season. As a result, grip strength and forearm soreness were only assessed in the spring pre-season data collection period.

All pitchers were on a prescribed number of innings for a given outing and threw a minimum of 45 pitches to a maximum of 90 pitches, depending on the stage of their progression established by the coaching staff. Eight pitchers were tested on 4 different occasions, all with 2 PCM cooling and 2 control outings each. Six pitchers were tested on 2 occasions, each with a PCM cooling and a control outing. One pitcher was tested on one occasion and received the PCM cooling treatment. One pitcher was tested on two occasions and received the control treatment both times.

Upper Extremity Strength Measures

Shoulder strength tests were performed using a hand-held dynamometer (Lafayette Instruments, Lafayette, IN). This dynamometer has a sensitivity of 0.1 kg and was calibrated before testing according to the manufacturer's recommendation. The validity and reliability of testing upper extremity strength with hand-held dynamometers have been well documented and the instrument has been used successfully in testing strength in professional, college and high school pitchers (7,18,19,20). The same tester performed all hand-held dynamometry strength tests and had over 20 years of experience making these specific measurements on baseball pitchers. All upper extremity manual strength tests were performed as break tests with the hand-held dynamometer force being applied proximal to the wrist joint. The average of 2 repetitions in each strength test was recorded for empty-can (EC), internal rotation (IR) and external rotation (ER). Tests were excluded as invalid if any pitcher reported pain during strength testing.

The EC test was performed in sitting without back support, with the arm at 90° of abduction and 30° anterior to the frontal plane with full glenohumeral IR. The pitcher stabilized himself by holding the seat with his nondominant arm during the test. The EC test position is thought to evaluate supraspinatus muscle strength (7,18,21). Shoulder IR and ER tests were performed with the subject in the supine position. Pitchers were placed with the shoulder in 90° of abduction (in neutral rotation) and elbow flexed at 90°. The dynamometer was placed on the dorsal or volar side of the wrist during the ER or IR test, respectively (7).

Grip strength measurements were taken in a standing position using a hydraulic hand dynamometer (Jamar, Performance Health, Warrenville, IL). Pitchers were instructed to have their shoulder adducted and neutrally rotated, elbow flexed at 90° and forearm in neutral position during the grip test. Pitchers were instructed to squeeze the dynamometer as hard as they could (isometric test).

Based on repeated measures of IR, ER, EC and grip strength on the nondominant arm of college pitchers (7) the relative minimal detectable changes were 16% for IR, 11% for ER, 13% for EC and 6% for grip strength.

Subjective Soreness Evaluation

On all three testing occasions, pitchers were asked to rate their current “shoulder” and “forearm” soreness on a scale of 0 to 10. A ranking of 0 indicated “no soreness” and 10 indicated “extreme soreness”.

Serum CK Measure

All blood samples were performed within the team facilities and obtained prior to any activity initiated by the participants. Thirty µL of capillary blood was obtained from the fingertip of the ring finger of the participant’s glove hand, for the enzymatic measurement of CK concentration. The fingertip was cleaned with 95% ethanol then allowed to dry completely before an automatic lancet device was used to draw blood from the finger. The first drop of blood was removed with cotton wool to prevent the sample from being contaminated with ethanol. A 30 µL pipette (Microsafe Tubule, Safe-Tec Clinical Products, Pennsylvania, USA) was used to collect the sample. The capillary blood sample was then immediately dispensed out of the pipette onto a CK test strip (Reflotron CK, Roche Diagnostics, Mannheim, Germany) and analyzed (Reflotron® Plus System, Roche Diagnostics, Basel, Switzerland).

Phase Change Material Application

Immediately following baseball activities, two rigid polyurethane PCM packs (4.5 in x 12 in; Glacier Tek LLC, Minneapolis, MN) frozen at 15°C were placed directly on the skin over the shoulder inside a compression shirt (IntelliSkin Foundation Tee, Newport Beach CA). One PCM pack was oriented on the anterior region of the shoulder complex, covering portions of the pectoralis, anterior and middle deltoid (Figure 1). The second pack, of the same size, was oriented on the posterior region of the shoulder complex covering portions of posterior deltoid, supraspinatus muscle belly and lateral portions of the infraspinatus muscle (Figure 1). A third pack, different from the first two PCM packs because it was flexible and made of a nylon material (4 in x 11 in; PureTemp LLC, Minneapolis, MN), was placed over the medial elbow and held in place with a graduated calf compression sleeve (Musetech, TN) to maintain its orientation. The PCM administered to the medial elbow was oriented proximal to the medial epicondyle and covered the flexor mass of the forearm (Figure 1). The flexible PCM packs were more suitable to applying across a joint because they could be conformed to the body part. The urethane PCM packs were rigid when frozen so were more suited to applying to flat areas. The urethane packs weighed 1 pound each; the nylon pack weighed 1.5 pounds.

Pitchers were instructed to leave the sporting venue and proceed with their post-game activities while continuing to wear the PCM cooling packs for 3 hours before removing them. Pitchers were contacted via text message two times over the course of the 3-hour application to verify both the orientation and the continued frozen state of the PCM. All participants were compliant with the 3-hour application.

Statistics

Force in each of the strength tests was expressed as a percentage of baseline in order to remove the effect of inter-individual variation in shoulder and forearm strength. The effect of postgame PCM cooling on strength, soreness and CK levels was assessed using treatment (PCM vs. control) by time (Pre, Day 1 post, Day 2 post) mixed model analysis of variance. Since not all pitchers had both treatments with matching numbers of pitches, treatment was applied as a between-subjects factor. Where there was a significant treatment effect, or treatment by time interaction, differences between treatments, or within groups, at any particular time interval were assessed using Bonferroni corrections for planned pairwise comparisons. Prior to employing ANOVAs, normality of distribution of all data sets were verified using the Shapiro-Wilk test. Creatine kinase values were not normally distributed and were log transformed, after which normal distribution was verified. Mauchly's test of sphericity was used to assess assumptions of sphericity and, where necessary, Greenhouse-Geisser corrections were applied to tests of within-subjects time effects. Cohen's *d* effect sizes are reported with 95% confidence intervals for treatment effects.

Baseline strength values were compared between the first and subsequent baseline measures to assess for potential learning effects with the strength tests. Most pitchers had previously performed the shoulder tests in routine preseason and post-season testing, but none had performed the grip test. If baseline values varied significantly for a particular test treatment order was added as a covariate to the ANOVA.

In order to assess the effect of pitch count on strength loss, soreness and CK activity, responses in the control condition were compared for outings where pitchers threw a low pitch count defined as <55 pitches (46±2, n=12) versus outings where pitchers threw a high pitch count defined as >70 pitches (78±7, n=12). These analyses were performed with pitch count (low vs. high) by time (Pre, Day 1, Day 2) mixed model ANOVA.

Statistical analyses were performed using SPSS v.21 (IBM, Armonk, NY, USA). Mean ± SD are reported in the tables and results section while Mean ± SE are reported in the figures. A P-value of less than 0.05 was considered statistically significant.

The study was powered to detect a difference in strength loss between PCM cooling and control. Based on the variability in IR and ER strength loss in college pitchers tested immediately after pitching a game (7) it was estimated that with 25 PCM cooling games versus 25 controls there would be 80% power to detect a 15% difference in percent strength loss between treatments at P<.05 (e.g. 5% strength loss with one treatment compared with 20% strength loss with a different treatment would be a 15% difference). Importantly, the strength tests from which the sample size estimate was made were performed by the same tester performing the tests in the present study. The detectable difference for EC strength loss was estimated to be 10%. The reported variability in post-game grip strength loss was much smaller and with 12 PCM cooling and 12 control games it was estimated that there was 80% power to detect an 11% difference in percent strength loss between treatments at P<.05 (7).

RESULTS

Total pitch count was not different between 23 PCM cooling games (60±16) and 24 control games (62±17; P=.679). Additionally, total pitch count was not different between the 11 PCM cooling games (74±9) and 13 control games (78±7; P=.219) in which flexible PCM was applied to the forearm in addition to the regular shoulder PCM packs.

Effect of PCM Cooling on Strength

Over the two days following pitching there was no loss of IR strength in the PCM treatment condition (P=.127) while there was marked IR strength loss for the control condition (Time effect P<.001; Treatment by Time P=.007; Fig. 2). Internal rotation strength was not significantly below baseline on either day after pitching in the PCM cooling treatment (Day 1: 95±14%, P=.184; Day 2: 100±13%, P=.999), but was below baseline on both days for control (Day 1: 83±13%, P<.001; Day 2: 92±12%, P=.006). Recovery of IR strength was greater in the PCM cooling condition versus the control condition on the first day after pitching (95% vs. 83%, P=.008, effect size *d* 0.91 95% CI 0.54-1.28).

After pitching there was ER strength loss in both the PCM cooling (P=.003) and control conditions (P<.001). However, ER strength loss tended to be less for the PCM cooling condition versus control (Treatment effect P=.091, effect size *d* 0.51 95% CI 0.19-0.83, Treatment by Time P=.174; Figure 3). ER strength was significantly reduced below baseline only on day 1 for PCM cooling treatment (93±9% of baseline; P=.002) and was below baseline on both days for the control condition (day 1: 86±13%, P=.002; day 2: 91±12%, P=.004).

Following pitching there was no loss in EC strength after the PCM cooling treatment (P=.803; day 1: 100±7%, day 2: 101±12%) and marginal strength loss after the control condition (P=.05; day 1: 95±12%, day 2: 99±10%), with no clear difference between PCM cooling and control conditions (Treatment effect P=.168; Treatment by Time P=.214).

There was a learning effect for grip strength such that baseline grip strength was 9% higher (P=0.045) on the second occasion on which pitchers were tested. Thus, baseline values for the initial treatment condition may have underestimated grip strength and thereby underestimated subsequent strength loss. Regardless of treatment condition, on the two days after pitching the first trial strength averaged 104% of baseline compared with 96% of baseline after the second trial. For the 24 games in which grip strength was measured, PCM cooling was the first treatment after 6 games and the second treatment after 5 games, while the control condition was first after 7 games and second after 6 games. Thus, treatment order was well balanced. However, to control for any potential confounding effects treatment order was added to the ANOVA as a covariate. On the days after pitching grip strength was higher with PCM cooling versus the control condition (Treatment effect P=.027, Treatment by Time P=.025; Fig. 4). One day after pitching grip strength was greater in the PCM treatment group (106±10% of baseline) than in the control condition (95±10%; P=.022, effect size *d* 1.29 95% CI 0.88-1.69).

The absolute strength values (Table 1) showed significant treatment by time effects for IR (P=0.006) and grip strength (P=0.039) with no effects for ER (P=0.208) or EC strength (P=0.112).

Soreness

Pitchers reported shoulder soreness on the days after pitching for both the PCM (P<.001) and control conditions (P<.001). The soreness response was not different between treatments (P=.947, Treatment by Time P=.885; Table 2). Shoulder soreness was highest one day after pitching but remained elevated above pre-game values on day 2.

Forearm soreness was elevated for both the PCM (P=.001) and control conditions (P=.002) and was not different between treatments (P=.134, Treatment by Time P=.206; Table

2). Forearm soreness was elevated above pre-game values one day after pitching but no longer on the second day.

Serum CK Activity

Data for serum CK were collected for 21 of 24 control games and 18 of 23 PCM cooling games due to unavailability of the CK instrumentation on some days. Over the two days following pitching CK_{log} increased in both the PCM condition (P=.016) and control condition (P<.001), with no difference between treatments (P=.549, Treatment by Time P=.139; Table 3).

Effect of Pitch Count on Markers of Muscle Damage

Surprisingly, strength loss was not different between low and high pitch count groups (IR: P=.996, ER: P=.645, EC: P=.887). Similarly, CK_{log} values and shoulder soreness values were not different between low and high pitch counts (P=.773, P=.233, respectively).

DISCUSSION

The purpose of this study was to assess recovery of strength, soreness and serum CK following a pitching performance and to determine whether recovery can be accelerated by providing prolonged post-game cooling to the shoulder and forearm. The results indicate that significant muscle damage occurs in collegiate level pitchers after throwing an average of 60 pitches and that recovery is incomplete two days after pitching. The results also indicated that recovery of strength was accelerated when 3 hours of cooling was applied, but PCM did not impact soreness or the CK response.

Muscle Damage Response to Pitching

In the present study strength loss and soreness in the dominant upper extremity, and CK fluctuations, were used as markers of muscle damage. Strength loss was the primary outcome measure because it is objective and specific to the demands of pitching. Soreness is subjective and CK measures can fluctuate if the athlete exercises other body parts strenuously as part of team conditioning. One study that previously examined strength loss on the days after pitching tested shoulder IR, ER and abduction strength one day after seven pitchers each threw 98 pitches (4). In their study IR and ER strength were highly variable and were not significantly different from baseline one day after pitching (averaged <10% strength loss)(4). Abduction strength was more consistent between players hence it was significantly reduced one day after pitching, but strength was less than 10% below baseline. There was comparably greater strength loss in the control condition of the present study. Strength loss one day after pitching was 17% for IR and 14% for ER. Both Yanagisawa et al and the present study used a hand-held dynamometer to assess strength; however, Yanagisawa et al used a “make” test to assess isometric strength while the present study used a “break” test (4). Tester experience with hand-held dynamometry for these tests, and within this athlete population, is very important. In the present study, the tester had 20+ years of strength testing baseball players.

The lack of EC strength loss on the days after pitching is consistent with a previous study in college pitchers in which there was no significant EC strength loss immediately postgame (7). Immediate postgame EC strength was 6±13% of baseline in the previous study compared with 5±12% one day after pitching for the control condition in the present study. There was also good agreement for IR and ER strength between the prior study on acute postgame fatigue and the present study on strength loss on the days after pitching. Postgame strength loss for IR and ER was 18±19% and 11±19%, respectively compared with 17±13% and 14±13% for the control condition one day after pitching in the present study (7). It is also notable that postgame fatigue in grip strength was 4±9% compared with 5±10% one day after pitching for the control condition in the present study (7). The consistency in these findings is surprising considering that an average of 99 pitches were thrown in the prior study while in the present study an average of 62 pitches were thrown (7).

Shoulder soreness one day after pitching in the control condition (3.2) was comparable to values for college pitchers reported by Yang et al (3.5) but values two days after pitching were much lower in the present study (1.8) compared with Yang et al (3.0) (5). Three days after pitching soreness values were close to baseline (1.0) (5). The difference in soreness two days after pitching likely reflects the number of pitches thrown (present study: 62 vs. Yang et al 2016: 105) (5); indicating that the greater pitch volume might prolong resolution of soreness without increasing peak soreness. Potteiger et al reported somewhat lower soreness (2.0) one day after 98 pitches and values close to baseline two and three days after pitching (2). By contrast, Yanagisawa et al reported greater soreness one day after 98 pitches (6.0) (4). However, participants in the Potteiger et al study completed an 18-day training regimen prior to pitching (2). On the other hand, Yanagisawa et al did not record data on subsequent days and their soreness assessment was a motion test as opposed to the general assessment made in the other studies, so direct comparison may not be appropriate (4). Similar to the pitchers in the preseason data collection period of the present study, Lazu et al showed no correlation between pitch volume and soreness in collegiate pitchers during a fall season (22).

The CK response in the present study was similar to prior studies that examined CK response in baseball pitchers, where CK peaked one day after pitching with lower values on subsequent days (2,5). Creatine kinase was elevated above baseline two days after 105 pitches (5) but only on one day after 62 pitches in the present study. The CK response to damaging exercise is highly individualized with high and low responders (23). Considering that baseball pitching is a multisegmental kinematic chain activity, the CK values following baseball pitching are not indicative of the muscle damage to the pitching arm alone but encompass systemic muscle damage. An additional issue confounding the CK response in the present study was that all pitchers were involved in conditioning exercises in addition to the pitches required for study completion. Thus, the CK values reflect muscle damage occurring from activities in addition the pitches necessary for this study. In-season CK responses may be different than those reported in the present study since pitchers are more likely to be well rested prior to games and a greater number of pitches would be thrown in games in the regular NCAA season.

PCM Cooling Intervention

Phase change material cooling improved IR strength and grip strength on the days after pitching with a trend toward improving ER strength. These benefits for strength recovery are in agreement with previous studies examining the effect of PCM cooling to the thighs after damaging quadriceps eccentric exercise and soccer matches (15,16,17). The lack of a significant effect of PCM cooling on ER strength may have been due to the orientation of the PCM packs.

The PCM pack on the posterior shoulder was above the spine of the scapula and may have more directly affected the temperature of the supraspinatus as opposed to the infraspinatus (Fig. 1). There was no loss of EC strength in the control condition; therefore, cooling of the supraspinatus could not have impacted strength recovery. The anterior PCM pack covered much of the pectoralis muscle and thus there was a likely benefit for IR strength. The elbow PCM pack covered most of the anterior aspect of the forearm including the medial elbow and thus there was a likely benefit for grip strength. The effect of PCM cooling on grip strength may have been confounded by an apparent learning effect whereby pitchers performed the test better on the second occasion (one day after pitching) regardless of the treatment condition. Thus, strength losses were less for the first condition tested because the initial test may not have represented a true maximal effort. Therefore, the true effect of PCM cooling on grip strength is best assessed by the comparison between treatments at a given time point as opposed to the changes versus baseline. One day after pitching the difference in grip strength loss between PCM cooling (106% of baseline) and control (95% of baseline) was 11%, representing a large effect size (1.29). A similarly large effect size (0.91) was seen for IR strength one day after pitching (PCM cooling 95% of baseline, control 83% of baseline, difference 12%).

The lack of effect from PCM cooling on soreness may be due to the low soreness values reported by all pitchers throughout the study duration. The benefits of PCM cooling for soreness in professional soccer players were not apparent until the second day after a game, when soreness was 6.3 for the control condition and 4.6 for PCM cooling. Comparably, the soreness values two days after pitching (shoulder: PCM cooling 1.7, control 1.8; forearm: PCM cooling 1.5, control 0.9) were much lower than two days after a soccer match. Although speculative, the pitchers participating in the present study were competing for a roster spot, and as a result they may have underreported their level of soreness.

CK elevations on the days after pitching were unaffected by postgame PCM cooling. These findings are in agreement with the only other study to have previously measured CK when examining the effectiveness of PCM for recovery following eccentric exercise (24). In both studies a small volume of muscle was exposed to the PCM cooling. Perhaps exposure to a cryotherapy modality that exerts a cooling stimulus to more of the body would have a greater effect on reducing CK. Cold water immersion involves cooling multiple muscle groups at once. However, a meta-analysis indicated only a small effect of cold-water immersion on recovery of CK (25).

Limitations

With respect to the damage response to pitching it is difficult to quantify the exact number and intensity of pitches thrown on a given day because different players warm up differently before throwing in a game and have differing number of pitches in the bullpen. It has been estimated that in high school baseball pitch counts underestimate the actual number of pitches thrown by over 40% (26). In the present study it was not possible to quantify the number of warm up pitches. However, this is the first study to examine the muscle damage response to pitching in actual games. Previous studies examining the muscle damage response used game simulations and while this allows a precise pitch count, the data in the present study are more ecologically valid for in-game responses (2,3,4,5). Additionally, the sample sizes in these previous studies ranged from 6-10 while in the present study the damage response was measured in 16 pitchers in 24 control games and 23 games with a recovery intervention (2,3,4,5). This is the largest muscle damage study in baseball pitchers to date.

Grip strength was assessed to represent the pitching stress on the muscles that can dynamically stabilize the medial elbow. In this regard, the flexor pronator mass is thought to provide dynamic stability to the medial elbow (27). However, a wrist flexion strength test may be a better test of flexor pronator mass strength and the potential for protection against medial elbow valgus stress. Specifically, wrist flexion fatigue (7.5% decrease in strength) has been shown to increase ultrasound measured medial elbow joint space with application of a valgus stress (28).

While PCM cooling can dramatically reduce muscle temperature and markedly improve strength recovery after damaging exercise, a limitation in this prior work is that the packs, when frozen, are solid and not conformable to joints (15,16,17,24). Thus, in the present study the packs did not conform as well with the shoulder as they did when placed over the anterior thighs in previous studies. A somewhat more conformable version of the PCM packs became available during the study and allowed the additional application on the forearm and elbow for the winter preseason data collection. These packs may prove more effective in providing more uniform cooling to the shoulder muscles in future applications. Alternatively, smaller PCM packs with smaller individual PCM cells are available and are more conformable to joints. However, the melt time is dependent on the size of the PCM cell, and packs designed for joints with smaller cells melt rapidly. The goal with using PCM cooling to accelerate recovery from stressful and damaging exercise is to provide prolonged cooling while allowing the athletes to continue their activities of daily living. The so-called secondary injury response after stressful exercise develops over several hours (29). Providing a prolonged continuous cooling intervention during this period is hypothesized to maximize the recovery benefits when compared to shorter duration interventions such as cold-water immersion or icing.

An additional limitation was that the control group did not receive icing to the shoulder or forearm. Although icing is a common practice in baseball, the team studied here did not routinely use post-game icing on their pitchers. Therefore, the choice was made to have the control condition what the routine practice was, and no player received post-game icing in this study. It is unknown if a 20- or 30-min post-game icing intervention would have a beneficial effect on recovery. It is noteworthy that all the pitchers in this study provided positive feedback on the comfort of the post-game PCM cooling intervention and adopted it as routine practice for the competitive NCAA season.

Finally, the use of a between-subjects analysis with a data set that has mostly, but not exclusively, within-subjects comparisons is problematic because the subjects are not all independent. However, in a within subjects model the samples were not correlated for between treatment comparisons of the primary dependent variables (strength loss). Thus, there was sufficient independence to warrant a between-subjects analysis.

Future Directions

Future studies should investigate responses to pitching full games with a higher pitch count than were reported here. Although it was recently reported that one session of PCM cooling does not inhibit the naturally occurring adaptive response to exercise, it remains known whether accelerating recovery with PCM cooling over multiple exercise sessions, such as in a baseball season, impacts subsequent performance or injury risk (23). Both areas warrant examination.

Conclusions

This is the largest study to date examining indices of recovery on the days after a baseball pitching performance. Prolonged PCM cooling protected against strength loss in shoulder IR and grip strength but did not affect CK levels or soreness. This is one of the first study to document impairments in muscle function on the days following baseball pitching, and the first study showing a novel intervention that accelerates recovery of muscle function in baseball pitchers. The effect of PCM cooling of the medial elbow and forearm on grip strength recovery is very encouraging considering the role the wrist flexors play in dynamic stability of the elbow.

Clinical Relevance

Phase change material cooling packs placed in compression garments provide a practical and effective means of delivering prolonged post-game cooling to the pitching shoulder and arm.

Acknowledgement

The results of this study are presented clearly, honestly and without fabrication, falsification or inappropriate data manipulation. The results of this study do not constitute endorsement by ACSM.

The authors would like to acknowledge the Kean University Athletic department and baseball program for their efforts in coordinating this project. There was no funding associated with this project or conflicts of interest in the products that were used. The authors purchased the commercially available rigid polyurethane PCM packs that were applied to the shoulder. The flexible nylon covered packs that were applied to the elbow were donated by PureTemp LLC, Minneapolis, MN as they were not yet commercially available.

REFERENCES

1. Pexa BS, Ryan ED, Hibberd EE, Teel E, Rucinski TJ, Myers JB. Infraspinatus cross-sectional area and shoulder range of motion change following live-game baseball pitching. *J Sport Rehab*. 2019;28:236-242.
2. Potteiger JA, Blessing DL, Wilson GD. Effects of varying recovery periods on muscle enzymes, soreness and performance in baseball pitchers. *J Athl Training*. 1992;27(1):27-31.
3. Yanagisawa O, Nitsu M, Takahashi Y. Magnetic resonance imaging of the rotator cuff muscles after pitching. *J Sports Med Phys Fit*. 2003;43(4):493-499.
4. Yanagisawa O, Miyanaga Y, Shiraki H, et al. The effects of various therapeutic measures on shoulder range of motion and cross-sectional areas of rotator cuff muscles after baseball pitching. *J Sports Med Phys Fitness*. 2003;43(3):356-66.
5. Yang S, Wang C, Lee S, et al. Impact of 12-s rule on performance and muscle damage of baseball pitchers. *Med Sci Sport Exerc*. 2016:2512-2516.
6. Hyldahl RD, Hubal MJ. Lengthening our perspective: morphological, cellular, and molecular responses to eccentric exercise. *Muscle Nerve*. 2014: 155-70.
7. Mullaney MJ, McHugh MP, Donofrio TM, Nicholas SJ. Upper and lower extremity muscle fatigue after a baseball pitching performance. *Am J of Sport Med*. 2006; 33(1):108-113.
8. Bishop SH, Herron RL, Ryan G, Katica CP, Biship PA. The effect of intermittent arm and shoulder cooling on baseball pitching velocity. *J Strength Cond Res*. 2016;30(4):1027-1032.
9. Verducci FM. Interval cryotherapy and fatigue in university baseball pitchers. *Res Q Exerc Sport*. 2001;72(3):280-287.

10. Warren CD, Szymanski DJ, Landers MR. Effects of three recovery protocols on range of motion, heart rate, rate of perceived exertion, and blood lactate in baseball pitchers during a simulated game. *J Strength Cond Res.* 2015;29(11):3016-3025.
11. Eston R, Peters D. Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *J Sports Sci*. 1999;17(3):231-238.
12. Schaser KD, Disch AC, Stover JF, et al. Prolonged superficial local cryotherapy attenuates microcirculatory impairment, regional inflammation, and muscle necrosis after closed soft tissue injury in rats. *Am J Sports Med.* 2007;35:93-102.
13. Tseng CY, Lee JP, Tsai YS, et al. Topical cooling (icing) delays recovery from eccentric exercise-induced muscle damage. *J Strength Cond Res.* 2013;27(5):1354-61.
14. Takagi R, Fujita N, Arakawa T, Kawada S, Ishii N, Miki A. Influence of icing on muscle regeneration after crush injury to skeletal muscles in rats. *J Appl Physiol*. 2011;110(2):382-8.
15. Kwiecien SY, McHugh MP, Howatson G. The efficacy of cooling with phase change material for the treatment of exercise-induced muscle damage: pilot study. *J Sports Sci*. 2018;36(4): 407-413.
16. Clifford T, Abbot W, Kwiecien SY, Howatson G, Mchugh MP. Cryotherapy reinvented: application of phase change material for recovery in elite soccer. *Int J Sports Phys Peform*. 2018;13:584-589.
17. Kwiecien SY, McHugh MP, Goodall S, Hicks KM, Hunter AM, Howatson G. Exploring the Efficacy of a Safe Cryotherapy Alternative: Physiological Temperature Changes from Cold Water Immersion vs Prolonged Phase Change Material Cooling. *Int J Sports Physiol Perform*. 2019;8:1-26.

18. Magnusson SP, Gleim GW, Nicholas JA. Shoulder weakness in professional baseball pitchers. *Med Sci Sports Exerc*. 1994;26:5-9.

19. Donatelli R, Ellenbecker TS, Ekedahl SR, Wilkes JS, Kocher K, Adam J. Assessment of shoulder strength in professional baseball pitchers. *J Orthop Sports Phys Ther*. 2000;19:125-159.

20. Tyler TF, Mullaney MJ, Mirabella MR, Nicholas SJ, McHugh MP. Risk factors for shoulder and elbow injuries in high school baseball pitchers: the role of preseason strength and range of motion. *Am J Sports Med*. 2014;42(8):1993-9.

21. Tadeda Y, Kashiwasguchi S, Endo K, Matsuura T, Sasa T. The most effective exercise for strengthening the supraspinatus muscle: evaluation by magnetic resonance imaging. *Am J Sports Med*. 2002;3:374-381.

22. Lazu A, Love S, Butterfield T, English R, Uhl T. The relationship between pitching volume and arm soreness in collegiate baseball pitchers. *Int J Sports Phys Ther*. 2019;14(1): 97-106.

23. Baird MF, Graham SM, Baker JS, Bickerstaff GF. Creatine-kinase- and exercise-related muscle damage implications for muscle performance and recovery. *J Nutr Metab*. 2012;1-13.

24. Kwiecien SY, O'Hara DJ, McHugh MP, Howatson G. Prolonged cooling with phase change material enhances recovery and does not affect the subsequent repeated bout effect following exercise. *Eur J Appl Physiol*. 2020;120(2):413-423.

25. Leeder J, Gissane C, van Someren KA, Gregson W, Howatson G. Cold water immersion and recovery from strenuous exercise: a meta-analysis. *Br J Sports Med*. 2012;46(4):233-240.

26. Zaremski J, Zeppieri G, Jones D, et al. Unaccounted workload factor; game-day pitch counts in high school baseball pitchers-an observational study. Ortho J Sports Med. 2018;6(4):1-7.

27. Park MC, Ahmad CS. Dynamic contributions of the flexor-pronator mass to elbow valgus stability. *J Bone Joint Surg Am*. 2004;86-A(10):2268-74.

28. Millard N, DeMoss A, McIlvain G, Beckett JA, Jasko JJ, Timmons MK. Wrist Flexion exercise Increases the Width of the Medial Elbow Joint Space During a Valgus Stress Test. *J Ultrasound Med*. 2019 Apr;38(4):959-966.

29. Armstrong RB, Warren GL, Warren JA. Mechanisms of exercise-induced muscle fibre injury. Sports Med. 1991;12:184-207.

Table 1. Absolute values for strength measures (Newtons, mean±SD)

	BASELINE		DAY 1		DAY 2		Treatment x Time
	Treatment	Control	Treatment	Control	Treatment	Control	
IR	212±33	229±47	200±38	191±52	211±42	210±46	P=0.006
ER	197±27	199±22	182±26	172±30	187±30	181±25	P=0.173
EC	147±21	151±22	147±21	142±19	148±23	148±22	P=0.112
GRIP	537±85	559±82	568±76	532±107	559±75	539±99	P=0.049

Figure 1: Shoulder and elbow/forearm PCM applications are shown in grey. Two rigid PCM packs applied at the shoulder were held in place by a compression shirt. One flexible PCM pack applied at the elbow was held in place by a compression sleeve.

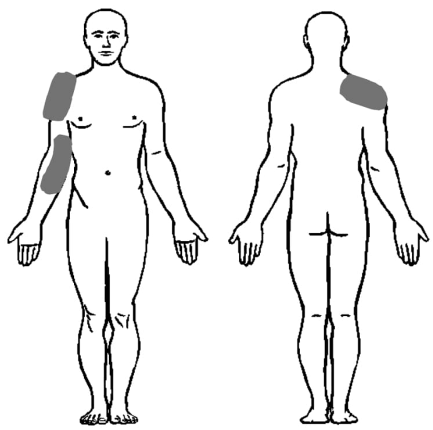

Figure 1

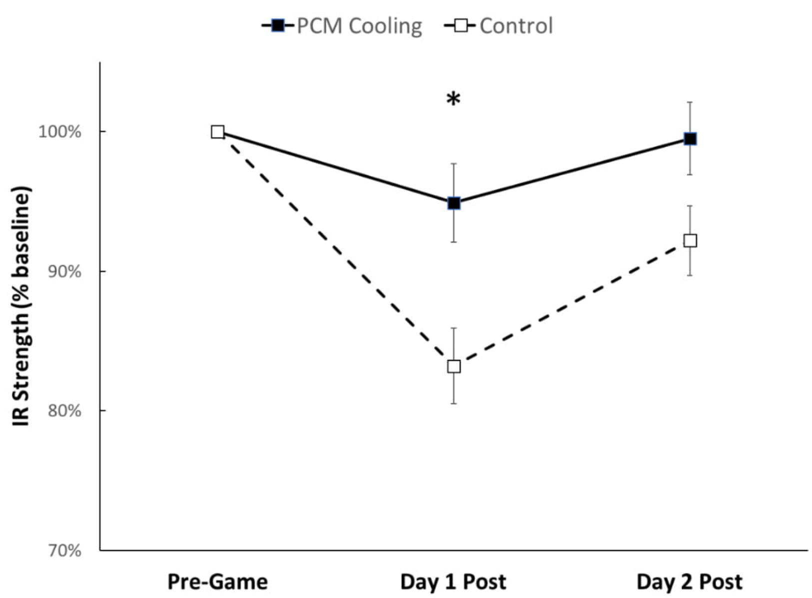

Figure 2

Figure 2: IR strength as percentage of baseline for PCM cooling and control conditions. Time effect P<.0001, Treatment effect P=.006, Treatment by Time P=.007. * Strength greater in PCM cooling condition versus control P=.008.

Figure 3: ER strength as percentage of baseline for PCM cooling and control conditions. Time effect P<.0001, Treatment effect P=.091, Treatment by Time P=.174.

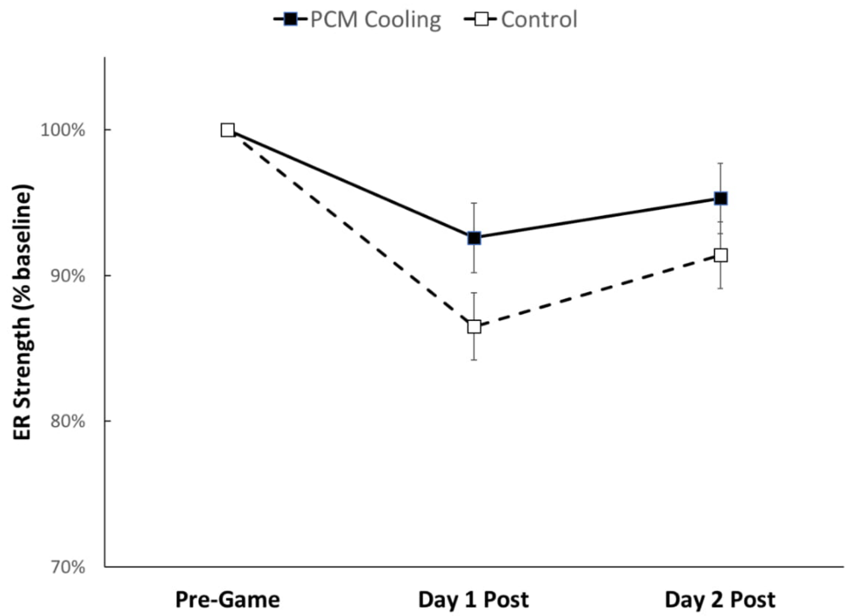

Figure 3

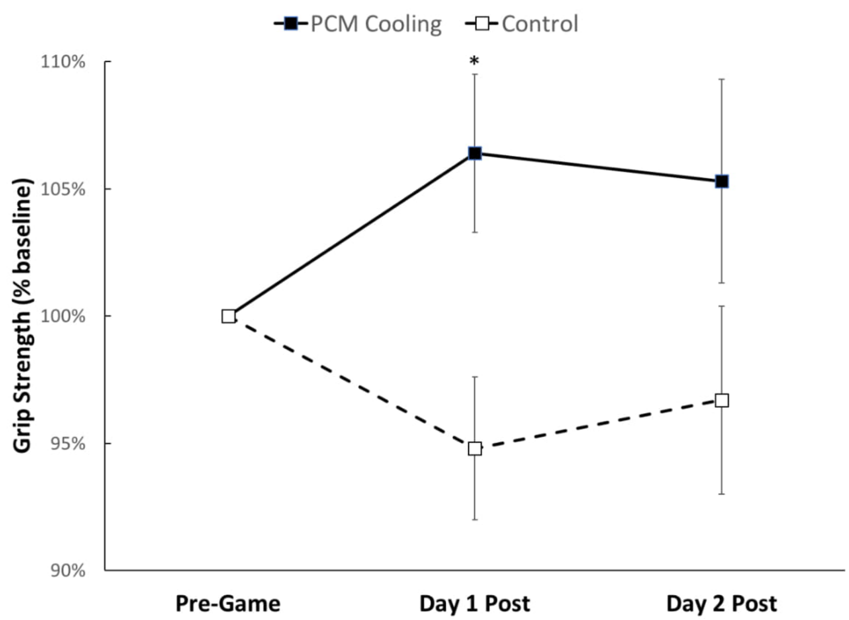

Figure 4

Figure 4: Grip strength as percentage of baseline for PCM cooling and control conditions. Time effect P=.904, Treatment effect P=.036, Treatment by Time P=.031. * Strength greater in PCM cooling condition versus control P=.022.