Accelerated Muscle Recovery in Baseball Pitchers Using Phase Change Material Cooling

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[1]Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, New York, NY; [2]Mullaney and Associates Physical Therapy, Matawan, NJ; [3]Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle upon Tyne, UNITED KINGDOM; [4]Athletics Department, Kean University, Union, NJ; and [5]Water Research Group, North-West University, Potchefstroom, SOUTH AFRICA

ABSTRACT

MULLANEY, M. J., M. P. MCHUGH, S. Y. KWIECIEN, N. IOVIERO, A. FINK, and G. HOWATSON. Accelerated Muscle Recovery in Baseball Pitchers Using Phase Change Material Cooling. *Med. Sci. Sports Exerc.*, Vol. 53, No. 1, pp. 228–235, 2021. **Purpose:** The purpose of this study was to document recovery after a pitching performance and determine whether prolonged postgame phase change material (PCM) cooling of the shoulder and forearm accelerates recovery. **Methods:** Strength, soreness, and serum creatine kinase (CK) activity were assessed before and on the 2 d after pitching performances in 16 college pitchers. Pitchers were randomized to receive either postgame 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 h. Strength was assessed for shoulder internal rotation (IR), external rotation (ER), empty can (EC) test, and grip. **Results:** Total pitch count was 60 ± 16 for 23 PCM cooling games and 62 ± 17 for 24 control games ($P = 0.679$). On the days after pitching, IR strength ($P = 0.006$) and grip strength ($P = 0.036$) 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 ($P = 0.008$, effect size $d = 0.91$) and 107% ± 9% versus 95% ± 10% for grip strength ($P = 0.022$, effect size $d = 1.29$). There was a trend for greater ER strength with PCM cooling ($P = 0.091$, effect size $d = 0.51$). The EC strength was not impaired after pitching ($P = 0.147$) and was therefore unaffected by PCM cooling ($P = 0.168$). Elevations in soreness and CK were not different between treatments (treatment–time CK $P = 0.139$, shoulder soreness $P = 0.885$, forearm soreness $P = 0.206$). **Conclusion:** This is one of the first studies to document impairments in muscle function on the days after baseball pitching, and the first study showing a novel cryotherapy intervention that accelerates recovery of muscle function in baseball pitchers after a game.

Key Words: CRYOTHERAPY, HANDHELD DYNAMOMETER, CREATINE KINASE, SORENESS

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) (1–5). 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). Because 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. (4) compared the effects of postgame icing, versus light exercise, versus the combination of icing plus light exercise, on strength and soreness 1 d after seven pitchers threw 98 pitches on three separate occasions. 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 (8–10). Ice applied to both the shoulder and the 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), and decrease ratings of perceived exertion and facilitate subjective recovery (8,9). These results are of limited relevance

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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.

Although postgame 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 postgame 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). In addition, in an animal model, prolonged direct cooling to muscle after a closed soft tissue injury reduced proliferation of the injury (12). By contrast, intermittent topical cooling over a 72-h period delayed recovery after bouts of eccentric exercise and in an animal model of muscle crush injuries icing impaired tissue repair (13,14).

The goal of postexercise cryotherapy interventions is to reduce the proliferation of tissue disruption. Repeated postexercise 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, postexercise 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 3 h. 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 makes 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 after baseball pitching, specifically examining strength recovery because only one previous small sample study has documented strength recovery in pitchers (4). The second purpose was to examine the effectiveness of postgame PCM cooling on indices of recovery in pitchers. Based on previous 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, and 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. Before 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 before and on each of the 2 d after a pitching performance. On days of data collection, data were obtained before 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 preseason (January/February). Because the flexible microsphere filling in the PCM pack applied at the elbow was a novel material made available after the initial data collection period (fall season), they were only applied in the spring preseason. As a result, grip strength and forearm soreness were only assessed in the spring preseason 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 four different occasions, all with two PCM cooling and two control outings each. Six pitchers were tested on two 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 handheld 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 the reliability of testing upper extremity strength with handheld dynamometers have been well documented, and the instrument has been used successfully in testing strength in professional, college, and high school pitchers (7,17–19). The same tester performed all handheld dynamometry strength tests and had over 20 yr of experience making these specific measurements on baseball pitchers. All upper extremity manual strength tests were performed as break tests with the handheld dynamometer force being applied proximal to the wrist joint. The average of two 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 (7,17,20). 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

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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 before any activity initiated by the participants. Thirty microliters 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, PA) 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).

PCM application. Immediately after baseball activities, two rigid polyurethane PCM packs (4.5 × 12 inches; 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 deltoid, and middle deltoid (Fig. 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 (Fig. 1). A third pack, different from the first two PCM packs because it was flexible and made of a nylon material (4 × 11 inches; 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 (Fig. 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, hence more suited to applying to flat areas. The urethane packs weighed 1 lb each; the nylon pack weighed 1.5 lb.

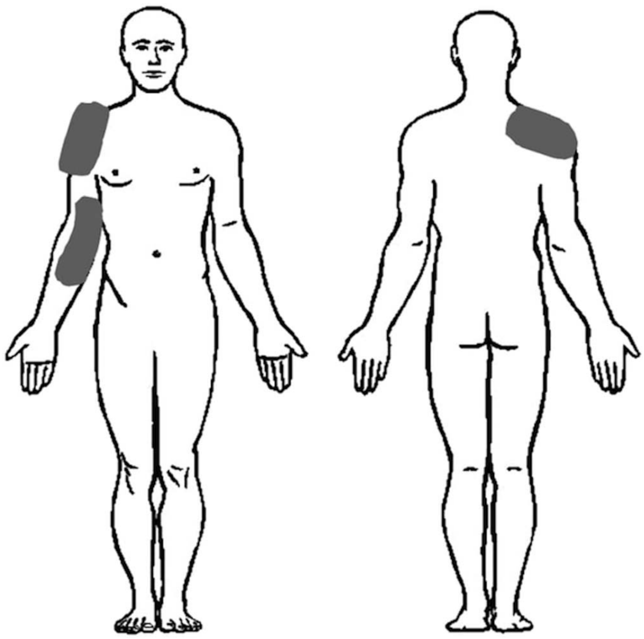

FIGURE 1—Shoulder and elbow/forearm PCM applications are shown in *gray*. Two rigid PCM packs applied at the shoulder were held in place by a compression shirt. One flexible PCM pack applied at the elbow was held in place by a compression sleeve.

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

Statistics. Force in each of the strength tests was expressed as a percentage of baseline to remove the effect of interindividual 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 ANOVA. Because 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–time interaction, differences between treatments, or within groups, at any particular time interval were assessed using Bonferroni corrections for planned pairwise comparisons. Before using ANOVA, normality of distribution of all data sets was verified using the Shapiro–Wilk test. CK 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 (CI) for treatment effects.

Baseline strength values were compared between the first and the subsequent baseline measures to assess for potential

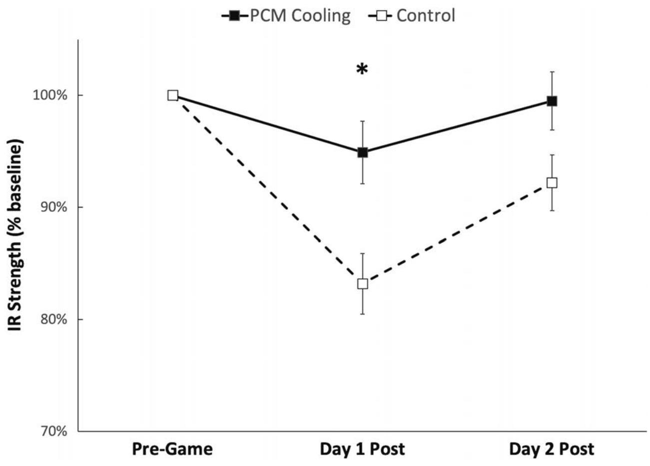

FIGURE 2—IR strength as percentage of baseline for PCM cooling and control conditions. Time effect *P* < 0.0001, treatment effect *P* = 0.006, treatment–time *P* = 0.007. *Strength greater in PCM cooling condition vs control *P* = 0.008.

learning effects with the strength tests. Most pitchers had previously performed the shoulder tests in routine preseason and postseason 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.

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, and day 2) mixed model ANOVA.

Statistical analyses were performed using SPSS version 21 (IBM, Armonk, NY). Mean ± SD values are reported in the tables and results section, whereas mean ± SE values 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* < 0.05 (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 postgame 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* < 0.05 (7).

RESULTS

Total pitch count was not different between 23 PCM cooling games (60 ± 16) and 24 control games (62 ± 17; *P* = 0.679). In addition, total pitch count was not different between the 11 PCM cooling games (74 ± 9) and 13 control games (78 ± 7; *P* = 0.219) 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 2 d after pitching, there was no loss of IR strength in the PCM treatment condition (*P* = 0.127), but there was marked IR strength loss for the control condition (time effect *P* < 0.001; treatment–time *P* = 0.007; Fig. 2). IR strength was not significantly below baseline on either day after pitching in the PCM cooling treatment (day 1: 95% ± 14%, *P* = 0.184; day 2: 100% ± 13%, *P* = 0.999), but it was below baseline on both days for control (day 1: 83% ± 13%, *P* < 0.001; day 2: 92% ± 12%, *P* = 0.006). 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* = 0.008, effect size *d* = 0.91, 95% CI = 0.54–1.28).

After pitching, there was ER strength loss in both the PCM cooling (*P* = 0.003) and the control conditions (*P* < 0.001). However, ER strength loss tended to be less for the PCM cooling condition versus control (treatment effect *P* = 0.091, effect size *d* = 0.51, 95% CI = 0.19–0.83, treatment–time *P* = 0.174; Fig. 3). ER strength was significantly reduced below baseline only on day 1 for PCM cooling treatment (93% ± 9% of baseline; *P* = 0.002) and was below baseline on both days for the control condition (day 1: 86% ± 13%, *P* = 0.002; day 2: 91% ± 12%, *P* = 0.004).

After pitching, there was no loss in EC strength after the PCM cooling treatment (*P* = 0.803; day 1, 100% ± 7%; day 2, 101% ± 12%) and marginal strength loss after the control condition (*P* = 0.05; day 1, 95% ± 12%; day 2, 99% ± 10%), with no clear difference between PCM cooling and control conditions (treatment effect *P* = 0.168; treatment–time *P* = 0.214).

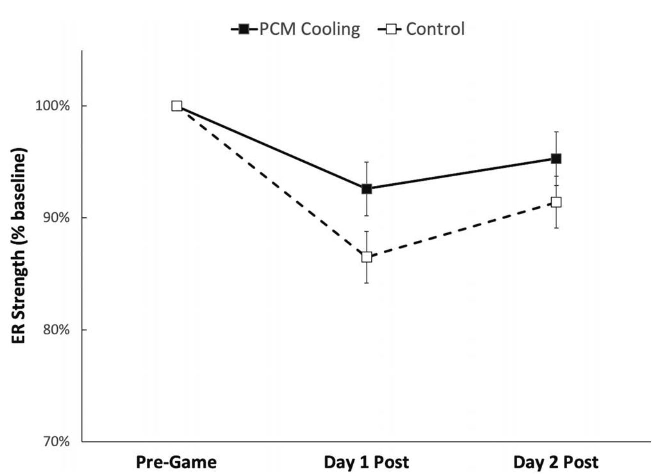

FIGURE 3—ER strength as percentage of baseline for PCM cooling and control conditions. Time effect *P* < 0.0001, treatment effect *P* = 0.091, treatment–time *P* = 0.174.

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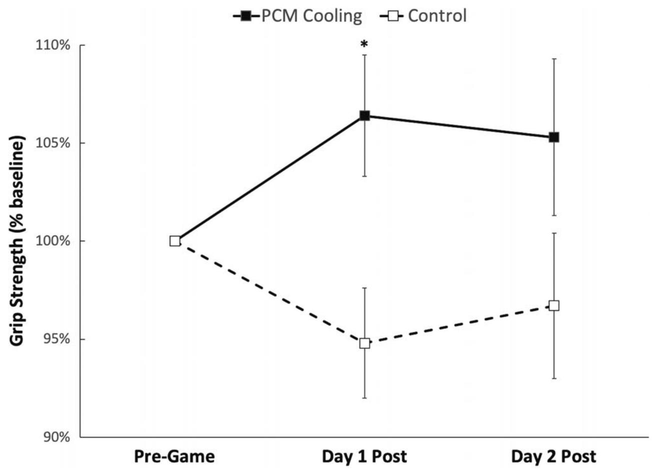

FIGURE 4—Grip strength as percentage of baseline for PCM cooling and control conditions. Time effect *P* = 0.904, treatment effect *P* = 0.036, treatment–time *P* = 0.031. *Strength greater in PCM cooling condition vs control *P* = 0.022.

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 2 d 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 six games and the second treatment after five games, whereas the control condition was first after seven games and second after six 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 $P = 0.027$, treatment–time $P = 0.025$; Fig. 4). One day after pitching, grip strength was greater in the PCM treatment group (106% ± 10% of baseline) than that in the control condition (95% ± 10%; $P = 0.022$, effect size $d = 1.29$, 95% CI = 0.88–1.69).

The absolute strength values (Table 1) showed significant treatment–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 ($P < 0.001$) and the control conditions ($P < 0.001$). The soreness response was not different between treatments ($P = 0.947$, treatment–time $P = 0.885$; Table 2). Shoulder soreness was highest 1 d after pitching but remained elevated above pregame values on day 2.

TABLE 2. Shoulder and forearm soreness for PCM cooling and control conditions (0–10 scale).

	Pre Game	Day 1 Post	Day 2 Post	Effect of Time
Shoulder PCM cooling	0.5 ± 0.9	3.3 ± 1.8*	1.7 ± 1.5*	$P < 0.001$
Shoulder control	0.4 ± 0.8	3.2 ± 1.8*	1.8 ± 1.6*	$P < 0.001$
Forearm PCM cooling	0.5 ± 1.2	3.2 ± 2.2*	1.5 ± 1.3	$P = 0.001$
Forearm control	0.4 ± 0.8	1.8 ± 1.7*	0.9 ± 1.2	$P = 0.002$

Data are presented as mean ± SD.
Shoulder: time effect $P < 0.001$, treatment effect $P = 0.947$, treatment–time $P = 0.885$.
Forearm: time effect $P < 0.001$, treatment effect $P = 0.134$, treatment–time $P = 0.206$.
*Significantly greater than Pre Game $P < 0.05$.

Forearm soreness was elevated for both the PCM ($P = 0.001$) and the control conditions ($P = 0.002$) and was not different between treatments ($P = 0.134$, treatment–time $P = 0.206$; Table 2). Forearm soreness was elevated above pregame values 1 d 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 because of the unavailability of the CK instrumentation on some days. Over the 2 d after pitching, CK_{log} increased in both the PCM condition ($P = 0.016$) and the control condition ($P < 0.001$), with no difference between treatments ($P = 0.549$, treatment–time $P = 0.139$; 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, $P = 0.996$; ER, $P = 0.645$; EC, $P = 0.887$). Similarly, CK_{log} values and shoulder soreness values were not different between low and high pitch counts ($P = 0.773$ and $P = 0.233$, respectively).

DISCUSSION

The purpose of this study was to assess recovery of strength, soreness, and serum CK after a pitching performance and to determine whether recovery can be accelerated by providing prolonged postgame 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 2 d after pitching. The results also indicated that recovery of strength was accelerated when 3 h of cooling was applied, but PCM did not affect 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.

TABLE 1. Absolute values for strength measures (newton, mean ± SD).

	Baseline		Day 1		Day 2		
	Treatment	Control	Treatment	Control	Treatment	Control	Treatment × Time
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	$P = 0.049$

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TABLE 3. CK_{log} values ($U \cdot L^{-1}$) for PCM cooling and control conditions.

	Pre Game	Day 1 Post	Day 2 Post	Effect of Time
PCM cooling	2.44 ± 0.25	2.59 ± 0.27*	2.51 ± 0.26	$P = 0.016$
Control	2.41 ± 0.36	2.72 ± 0.23*	2.55 ± 0.21	$P < 0.001$

Data are presented as mean ± SD.
Time effect $P < 0.001$, treatment effect $P = 0.549$, treatment–time $P = 0.139$.
*Significantly greater than Pre Game $P < 0.05$.

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 1 d after seven pitchers each threw 98 pitches (4). In their study, IR strength and ER strength were highly variable and were not significantly different from baseline 1 d after pitching (averaged <10% strength loss) (4). Abduction strength was more consistent between players; hence, it was significantly reduced 1 d 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 1 d after pitching was 17% for IR and 14% for ER. Both Yanagisawa et al. (4) and the present study used a handheld dynamometer to assess strength; however, Yanagisawa et al. (4) used a "make" test to assess isometric strength while the present study used a "break" test. Tester experience with handheld dynamometry for these tests, and within this athlete population, is very important. In the present study, the tester had 20+ yr 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% 1 d after pitching for the control condition in the present study. There was also good agreement for IR and ER strength between the previous 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 1 d after pitching in the present study (7). It is also notable that postgame fatigue in grip strength was 4% ± 9% compared with 5% ± 10% 1 d 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 previous study, whereas an average of 62 pitches were thrown in the present study (7).

Shoulder soreness 1 d after pitching in the control condition (3.2) was comparable to values for college pitchers reported by Yang et al. (3.5), but values 2 d 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 2 d after pitching likely reflects the number of pitches thrown (present study, 62, vs Yang et al. (5), 105), indicating that the greater pitch volume might prolong the resolution of soreness without increasing peak soreness. Potteiger et al. (2) reported somewhat lower soreness (2.0) 1 d after 98 pitches and values close to baseline 2 and 3 d after pitching. By contrast, Yanagisawa et al. (4) reported greater soreness 1 d after 98 pitches (6.0). However, participants in the Potteiger et al. (2) study completed an 18-d training regimen before pitching. On the other hand, Yanagisawa et al. (4) 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. Similar to the pitchers in the preseason data collection period of the present study, Lazu et al. (21) showed no correlation between pitch volume and soreness in collegiate pitchers during a fall season.

The CK response in the present study was similar to previous studies that examined CK response in baseball pitchers, where CK peaked 1 d after pitching with lower values on subsequent days (2,5). CK was elevated above baseline 2 d after 105 pitches (5), but only on 1 d after 62 pitches in the present study. The CK response to damaging exercise is highly individualized with high and low responders (22). Considering that baseball pitching is a multisegmental kinematic chain activity, the CK values after 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 because pitchers are more likely to be well rested before games and a greater number of pitches would be thrown in games in the regular NCAA season.

PCM cooling intervention. PCM 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 (15,16,23). 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 affected 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 (1 d 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.

APPLIED SCIENCES

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 1 d 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 2 d after pitching (shoulder: PCM cooling 1.7, control 1.8; forearm: PCM cooling 1.5, control 0.9) were much lower than 2 d 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 after 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 although this allows a precise pitch count, the data in the present study are more ecologically valid for in-game responses (2–5). In addition, the sample sizes in these previous studies ranged from 6 to 10, whereas in the present study, the damage response was measured in 16 pitchers in 24 control games and 23 games with a recovery intervention (2–5). 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).

Although PCM cooling can dramatically reduce muscle temperature and markedly improve strength recovery after damaging exercise, a limitation in this previous work is that the packs, when frozen, are solid and not conformable to joints (15,16,23,24). 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 with 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 postgame icing on their pitchers. Therefore, the choice was made to have the control condition what the routine practice was, and no player received postgame icing in this study. It is unknown if a 20- or 30-min postgame 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 postgame 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 unknown whether accelerating recovery with PCM cooling over multiple exercise sessions, such as in a baseball season, affects subsequent performance or injury risk (22). 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 after 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. PCM cooling packs placed in compression garments provide a practical and effective means of delivering prolonged postgame cooling to the pitching shoulder and arm.

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