

Cryotherapy duration is critical in short-term recovery of athletes: a systematic review

Alexander H Jinnah,¹ Tianyi David Luo,¹ Christopher Mendias,² Michael Freehill³

¹Orthopaedic Surgery, Wake Forest Baptist Medical Center, Winston-Salem, North Carolina, USA

²Orthopaedic Surgery, Hospital for Special Surgery, New York, New York, USA

³Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, USA

Correspondence to

Dr Alexander H Jinnah;
ajinnah@wakehealth.edu

Received 4 October 2018

Revised 11 April 2019

Accepted 2 May 2019

Published Online First

23 June 2019

ABSTRACT

Importance Cryotherapy is one of the simplest and oldest therapeutic methods used to alleviate acute soft tissue trauma and muscle soreness. However, inconsistent outcomes have been reported due to inconsistent protocols.

Objective To determine if various cryotherapy methods lead to enhanced recovery in athletes and identify optimal methods and protocol for short-term recovery in athletes.

Evidence review PubMed/MEDLINE and SPORTDiscus databases were searched from 1 April 1950 to 31 December 2018. The search algorithm used was: (Icing OR Ice Therapy OR Cryotherapy) AND (Athlete OR Sports) NOT (Case Reports). Inclusion criteria was human clinical studies with level 1–4 evidence, a cohort of at least 20 athletes, who were followed to determine the effect cryotherapy had on performance, pain and/or recovery were included. Abstracts, reviews, case reports and conference proceedings were excluded. Seven studies investigating the effect cryotherapy recovery were included. Manual extraction and compilation of demographic, methodology, functional and biochemical outcomes from the studies were completed. Non-randomised trials were assessed using the Methodological Index for Non-Randomised Studies and the randomised were assessed using Oxford quality scoring system.

Findings Decreased pain or muscle soreness was seen with cold water immersion (CWI) when compared with passive recovery. Other outcome variables assessed (biomarkers, functional tests) did not reveal consistent findings. Longer icing times (>10 min) were associated with detrimental effects in muscle power and activity.

Conclusions and relevance Duration is the critical variable in conventional cryotherapy, with prolonged icing leading to immediate detriment in muscle power and activity. Thus, we recommend using ice cryotherapy following exercise for no longer than 10 min for pure hypoalgesia. CWI had a greater benefit on recovery than passive recovery. Furthermore, CWI has a more beneficial effect on recovery in the first 24 hours following exercise versus immediately postrecovery. We recommend using a protocol to include immersion times of 11–15 min in 11°C–15°C (52°F–59°F) water.

Level of evidence Level III.

INTRODUCTION

Cryotherapy (CT) is one of the simplest and oldest therapeutic methods used to alleviate acute soft tissue trauma, pain and muscle soreness.^{1 2} It has been used to accelerate recovery in athletes following exercise for decades.^{1 3–6} The scientific reasoning behind CT is to decrease tissue surface

What is already known

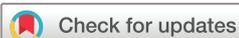
- ▶ Cryotherapy leads to a reduction in pain and inflammation by decreasing metabolite concentrations within soft tissues.

What are the new findings

- ▶ Conventional icing of long durations (>10 min) is detrimental to immediate muscle power and activity, and should only be used for hypoalgesia.
- ▶ Cold water immersion cryotherapy for 11–15 min at 11–15°C has a beneficial effect on recovery that is greatest 24 hours after the cryotherapy.

temperature to minimise hypoxic cell death, oedema formation and muscle spasms, all of which ultimately reduce pain and inflammation.^{7–13} CT is a broad term encompassing the use of cold temperatures as a medical therapy. Under this broad umbrella, therapies have ranged from simple ice packs and cold water immersion (CWI) to more sophisticated methods of whole body cryotherapy (WBC).^{2 14–19}

Conventional local CT, for example, ice packs, exerts its effect by decreasing the intramuscular temperature by 3°C–8°C (37°F–46°F), thus decreasing the levels of metabolites in the tissue.²⁰ Alternatively, systemic forms of CT (CWI and WBC) have recently grown in popularity.^{16 21} They aim to decrease intramuscular temperature by up to 6°C (49°F) and also lead to a decrease in core temperature of up to 2°C (36°F).²² WBC is the most recent technique of CT to be introduced to the athletic world and involves exposing individuals to extremely cold temperatures (<–100°C (–148°F)) for a short period of time. It is thought that the extreme temperatures will stimulate cutaneous receptors and excite the sympathetic adrenergic system leading to reduced muscle metabolism, skin microcirculation, receptor sensitivity and nerve conduction velocity.²³ The decrease in core temperature leads to changes in circulating levels of catecholamines and cytokines,²⁴ which exert a predominantly parasympathetic modulation of heart rate, a vital physiologic reaction necessary to initiate cardio-deceleration and to complete the recovery.^{24 25} The outcomes of these therapies have varied due to the lack of consistency in CT time and temperatures as well as variations in body composition.^{14 16 19 26 27} Consequently, some



© International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine 2019. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Jinnah AH, Luo TD, Mendias C, et al. *JISAKOS* 2019;**4**:131–136.

authors have questioned the efficacy of CT on exercise recovery in athletes.^{28–30}

Due to variations in the type and duration of CT and the lack of consistent recommendations for its use in the existing literature, we conducted a qualitative systematic review to determine the existing therapeutic protocols and their effectiveness in athletes. Specifically, we sought to answer the following questions:

1. Does conventional ice therapy performed within 1 hour of exercise aid in recovery to baseline performance immediately post-therapy and at 24 hours post-therapy?
2. Does any alternative CT performed within 1 hour of exercise aid in recovery to baseline performance immediately post-therapy and at 24 hours post-therapy?

Answers to these questions will allow recommendations to be made for postgame exercise competition CT and for the optimal CT for athletes that need to perform competition on a daily basis (baseball position players, hockey players, etc).

METHODS

Literature search

A systematic review was conducted according to Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) guidelines using a PRISMA checklist.³¹ A review of the published English language literature assessing the short-term recovery in athletes was performed using PubMed/MEDLINE and SPORTDiscus databases. The search algorithm used was as follows: (Icing OR Ice Therapy OR Cryotherapy) AND (Athlete OR Sports) NOT (Case Reports). Inclusion criteria was human clinical studies from 1 April 1950 to 31 December 2018 with level 1 through 4 evidence,³² a cohort of athletes (amateur, high school, collegiate or professional), who were followed to determine the effect CT had on performance, pain and/or recovery. Exclusion criteria included abstracts, reviews, case reports, conference proceedings, animal studies, investigation not in English and use of a non-athlete population. Studies were then divided into two categories: conventional ice CT and alternative CT programmes. Studies which assessed the athlete immediately following (within 1 hour) and/or 24 hours after CT were included for analysis. Non-randomised trials were assessed using the Methodological Index for Non-Randomised Studies (MINORS)³³ and the randomised were assessed using the Oxford quality scoring system.³⁴

Alternative CT methods included CWI and WBC. CWI consists of a specific region of the body being submerged in temperature controlled water (usually 5°C–15°C (41°F–59°F)) for a predetermined time (usually 5–20 min). WBC entails an exposure of the entire body to extremely cold temperatures (<–100°C (–148°F)) for 2–4 min.

Data collection

Two reviewers (AHJ and TDL) independently extracted suitable data from the studies meeting inclusion criteria. Appropriate data included any physical or biochemical outcome which assessed the efficacy of the cooling modality immediately and/or 24 hours after cooling. Sample size and demographic data were also extracted from each study. The two reviewers then compared their findings and any variation was settled by the senior author (MTF).

RESULTS

Literature search

Seven studies met the inclusion and exclusion criteria for review (figure 1). The included studies involved a total of 180 athletes with a mean age of 22.2 years (range 15–32).

Conventional ice cryotherapy

Three of the seven studies with level 1 and 2 evidence assessed the efficacy of conventional ice CT on recovery in 93 subjects with a mean age of 22.9 years (table 1).^{35–41}

All of these studies investigated the immediate effect icing had on biomarkers, soreness, or athletic performance. The duration of icing application among these studies ranged from 3 to 30 min.

Subjective muscle soreness and pain were assessed by Behringer *et al*⁴² (table 2). It was noted that there was no difference in delayed onset muscle soreness (DOMS), despite the known hypoalgesic properties associated with conventional CT.^{1,43}

Functional performance was assessed by the remaining investigations.^{39,44} Fischer *et al* found that 10 min of local CT impaired power and functional performance immediately following CT, but that shorter durations (3 min) had no effect. Similarly, Lee *et al*⁴⁴ observed a decrease in countermovement jump height following local CT for 20 min. A summary of the findings in these studies can be found in table 2.^{39,42,44}

Data obtained from these trials varied in its reliability as judged by the MINORS criteria or the Oxford quality scoring system. Fischer *et al*³⁹ was the only non-randomised trial included and can be determined to have a MINORS criteria score of 20/24, indicating a low risk of bias. However, Behringer *et al*⁴² and Lee *et al*⁴⁴ had a Oxford quality score of 1/5 and 2/5, respectively. This indicates that the randomised studies were of poor quality.

Alternative cryotherapy

Four studies of level 1 or 2 evidence evaluated 87 subjects with a mean age of 21.3 years with respect to physical recovery following alternative CT methods (table 3).^{45–48}

Of the four studies, three assessed the effect of CT immediately and 24 hours following therapy,^{46–49} and one assessed the recovery at 24 hours only.⁴⁵

Cold water immersion

Ascensão *et al*⁴⁶ and Doeringer *et al*⁴⁵ directly compared the effects of CWI with passive recovery, while Elias *et al* and Webb *et al* compared CWI with contrast water therapy (CWT).^{47,48} Our review demonstrated that CWI had a general positive effect on physical performance and biomarkers. DOMS was assessed in two studies,^{45,46} while perception of muscle soreness/exertion was assessed in the remaining two.^{47,48} Despite the differing protocols, all investigations concluded that soreness was decreased in the CT groups when compared with their control group.

Biochemical markers representing muscle damage, for example, creatine kinase (CK), myoglobin and C reactive protein were investigated in two of the studies.^{46,48} Both of these demonstrated a significant improvement following CWI. Furthermore, varying functional tests were commonly used as outcome variables. Elias *et al*⁴⁷ found an improvement in functional tests with CT, however, Ascensão *et al*⁴⁶ and Doeringer *et al*⁴⁵ observed mixed results.

Assessment of quality of the randomised studies done using the Oxford quality scoring system demonstrated that these investigations were all of poor quality with scores of 1/5 in all cases except for Doeringer *et al* (score of 2/5).

DISCUSSION

The present study reviewed the existing literature regarding different methods of CT in athletes following exercise to evaluate the evidence and make recommendations regarding protocols to maximise recovery. Our results demonstrated a variety of CT protocols and an array of outcome variables used to

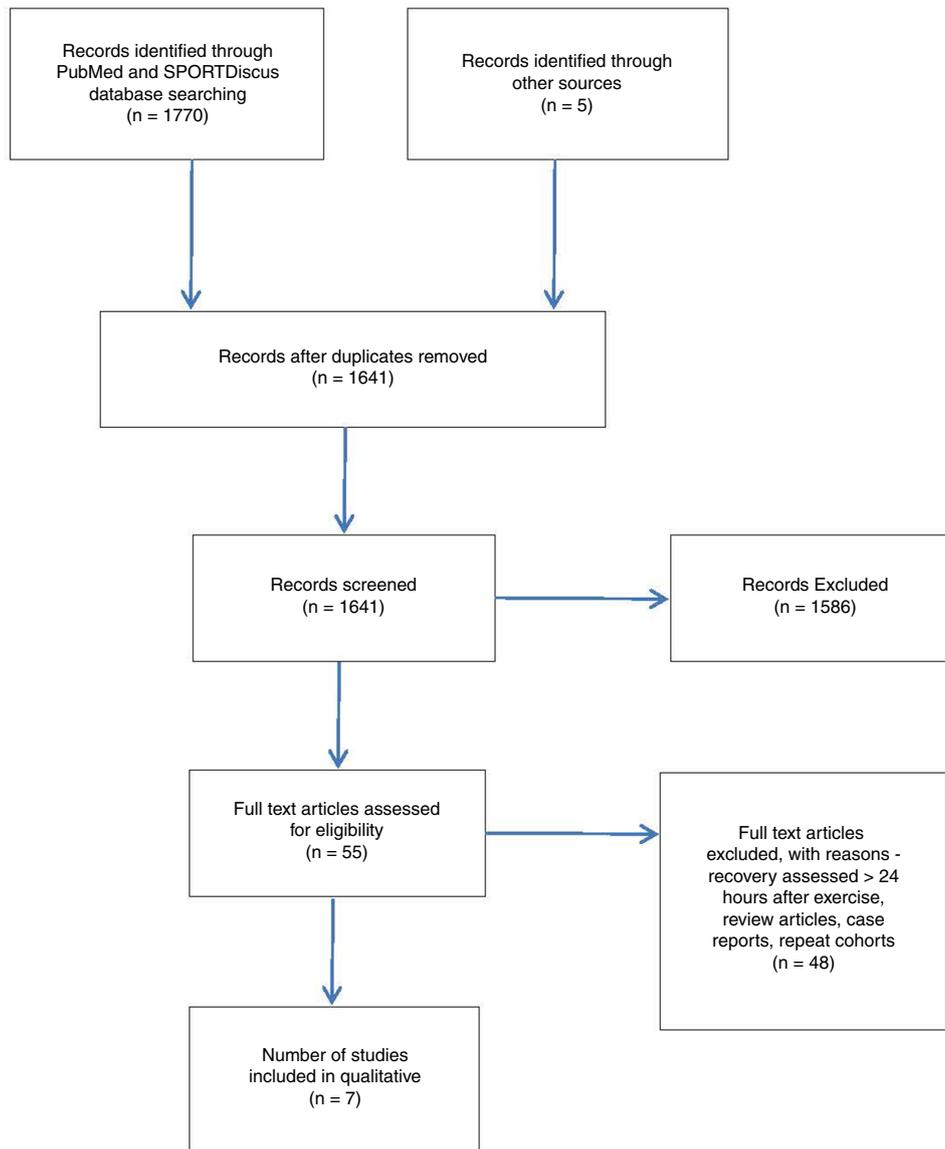


Figure 1 Preferred Reporting Items for Systematic reviews and Meta-Analyses flow diagram.

assess the efficacy of CT following exercise. Outcome variables assessed demonstrated that CWI had the greatest positive impact on recovery.

Conventional ice cryotherapy

Overall, the current literature investigating the effect of conventional CT on recovery in athletes demonstrated no impact or a negative one on an athlete's performance.^{39 42 44} However, it is important to note that these studies all had varying methodologies and protocols used for CT. Furthermore, in order to maintain consistency within the studies, the athletes were required to strictly adhere to their recovery modalities with no adjunctive measures. This may not be reproducible, because in

reality athletes may choose to use additional recovery methods as adjuncts to improve performance and recovery.

The reason for conventional CT demonstrating negative impacts on recovery may be due to CT duration. All of the investigations included in our review used CT times of at least 10 min, except for one cohort within the study by Fischer *et al.*³⁹ Interestingly in this cohort, the authors found a change from a detrimental impact on recovery to having no effect. Short-term, intermittent icing is a method of CT that has been implemented by several authors for in game use for baseball pitchers.^{37 38 50 51} The authors demonstrated a positive effect on innings pitched, velocity and accuracy. Recovery after 24 hours was assessed by Yanagisawa *et al.*^{37 38} following implementation of a light

Table 1 Conventional icing times and demographics

Study	Year published	Level of evidence	Participants	Mean age (years)	Icing time (min)	Primary/secondary outcomes
Fischer <i>et al.</i> ³⁹	2009	2	42	22.2	3 or 10	Shuttle run, co-contraction test and vertical jump
Lee <i>et al.</i> ⁴⁴	2017	1	21	21	20	CMJ or SJ height
Behringer <i>et al.</i> ⁴²	2018	1	30	25.7	30	CK, h-FABP, DOMS

CK, creatine kinase; CMJ, countermovement jump; DOMS, delayed onset muscle soreness; h-FABP, fatty acid binding protein; SJ, squat jump.

Table 2 Conventional icing studies outcome variables and results

Study	Outcome variables	Results
Fischer <i>et al</i> ³⁹	Shuttle run, co-contraction test and vertical jump	Power (vertical jump) was impaired immediately and 20 min after 10 min ice bag application to the hamstrings, whereas a shorter duration of ice application had no effect on these tasks.
Lee <i>et al</i> ⁴⁴	CMJ or SJ height	CMJ height decreased immediately after ankle and knee cryotherapy, no change was seen in the rest group. CMJ height returned to baseline 10 min after CT.
Behringer <i>et al</i> ⁴²	CK, h-FABP, DOMS	No difference in DOMS was observed between MLD, icing or rest.

CK, creatine kinase; CMJ, countermovement jump; CT, cryotherapy; DOMS, delayed onset muscle soreness; h-FABP, fatty acid binding protein; MLD, manual lymphatic drainage; SJ, squat jump.

shoulder exercise protocol in combination with icing, resulting in an increase in range of motion and strength recovery. These studies were limited by the small cohorts, and thus did not meet inclusion criteria for our study, but demonstrated that short and intermittent conventional CT may be the key to immediate (eg, in game) and prolonged recovery when combined with light stretching after the game.

It appears a prolonged icing time (10 min or greater) can lead to an immediate detriment in muscle power and activity, with shorter icing times having a possible beneficial effect on these variables. Thus, the athlete or athletic trainer must have the goal in mind before determining the duration of the conventional CT. Short intermittent CT applications during sporting competition, although only reported small cohort studies,^{36–38 51} could provide benefits, whereas the traditional longer duration of icing clearly demonstrates no impact or immediate detriment with the intention of recovery the day after competition. Longer duration CT may be more suitable for strict short-term hypoalgesia due to its known short-term hypoalgesic properties in conjunction with this effect dissipating by 24 hours post-therapy.^{1 43 52}

Alternative cryotherapy

Cold water immersion

Our investigation demonstrated that CWI had a positive impact on athletic performance and DOMS. Similarly, two prior systematic reviews concluded that there was some evidence that CWI decreased muscle soreness when compared with passive interventions, however no other conclusions could be made.^{15 53} Alternatively, Paddon-Jones and Quigley investigated CWI in weight training and found there to be no beneficial effect when compared with rest.⁵⁴ The difference seen in this trial may be due to the extended duration of 20 min of immersion in conjunction with this study being underpowered with a sample size of 8.

CWI was found to have a more beneficial effect on recovery in the first 24 hours following exercise instead of an immediate impact on recovery. Accordingly, the meta-analysis performed by Machado *et al*⁵³ investigating CWI concluded that this method of recovery may be slightly better than passive recovery in the management of muscle soreness. The authors recommended using a protocol to include an immersion time of 11–15 min in water that is 11°C–15°C (52°F–59°F), which we agree provides the best opportunity for success for recovery 24 hours post-therapy. Based on our findings, we recommend this protocol for optimal recovery in DOMS and physical activity up to 24 hours following exercise and CT.

In accordance with the variations in biochemical markers found by Webb *et al*,⁴⁸ Vanderlei *et al*⁵⁵ recently published a report which found that different biochemical markers (lactate and CK) take between 72 and 96 hours to fully recover with varying methods and timing of CWI. Due to the scope of this review only including results up to 24 hours after the initial therapy, we would not expect to see consistent differences in CWI versus passive recovery at this short time point. Furthermore, Vanderlei *et al*⁵⁵ noted that 15 min of CWI resulted in the greatest decrease in CK. The findings by Webb *et al*⁴⁸ may be due to the shorter duration (5 min) of CT. Based on these results and the benefit noted with DOMS, we postulate that using CWI as a recovery method may be of greater benefit to athletes with greater time periods between games (eg, football players, baseball starting pitchers) versus athletes that are required to perform in competition on a daily basis (eg, baseball position players, hockey players).

An alternative to CWI that is gaining popularity, but negates the CT effect of CWI is a method called contrast water therapy. This can be considered an extension of CWI with repetitive application of cold and hot water alternatively. The theory behind the

Table 3 Alternative cryotherapy times and demographics

Study	Year published	Level of evidence	Participants	Mean age (years)	Therapy	Cryotherapy time (min)	Primary/secondary outcomes
Ascensão <i>et al</i> ⁴⁶	2011	1	20	Not listed	Cold water immersion	10	DOMS, biochemical markers, performance tests
Elias <i>et al</i> ⁴⁷	2013	1	24	19.9	Cold water immersion	14	Perceived measures, jump performance, repeat sprint testing
Webb <i>et al</i> ⁴⁸	2013	2	21	23.5	Cold water immersion	5	PMS, CMJ, CK
Doeringer <i>et al</i> ⁴⁵	2018	1	22	20.6	Cold water immersion	25	DOMS, flexibility, CMJ, shuttle, 10m dash

CMJ, countermovement jump height; CK, creatine kinase; DOMS, delayed onset muscle soreness; PMS, perceptual muscle soreness.

Table 4 Alternative cryotherapy study outcome variables and results

Study (CT used)	Outcome variables	Results
Ascensão <i>et al</i> ⁴⁶ (CWI)	DOMS, biochemical markers, performance tests	Decrease in quadriceps (24 hours), calf (24 hours) and adductor (30 min) DOMS with CWI.
Elias <i>et al</i> ⁴⁷ (CWI)	Perceived measures, jump performance, repeat sprint testing	Perceived muscle soreness and fatigue: CWI and CWT vs control 24 hours postmatch was lower; CWI was lower than control at 1 hour postexercise; CWI was lower vs CWT at 1 and 24 hours postexercise.
Webb <i>et al</i> ⁴⁸ (CWI)	PMS, countermovement JH, CK	Both CWT and CWI had significantly reduced PMS. CWT is likely to have clear recovery benefits on PMS vs CWI 18 hours postexercise.
Doeringer <i>et al</i> ⁴⁵ (CWI)	DOMS, flexibility, CMJ, shuttle, 10 m dash	Speed increased 5.3% with CWI, compared with decrease of 5% in control.

CK, creatine kinase; CMJ, countermovement jump; CRP, C reactive protein; CT, cryotherapy; CWI, cold water immersion (regional); CWT, contrast water therapy; DOMS, delayed onset muscle soreness; JH, jump height; PMS, perceptual muscle soreness; WBC, whole body cryotherapy (whole body).

benefits of CWT derives from decreased oedema and metabolite production from the cold, with the reduction of pain and muscle spasm with promotion of soft tissue healing with heat.^{56,57} This is often thought of as a flushing of the soft tissues of the affected region. Two of the articles included in this review compared CWT with CWI^{47,48}; however, the protocols used varied. This variation in protocols used is most likely responsible for the variation in results seen.^{47,48,58} It can be postulated that these differences are due to the difference in time of CWI; however, this conclusion cannot be made due to the lack of a consistent protocol in the literature. Contrast water therapy remains an intriguing alternative form of recovery in athletes that should continue to be studied, but due to the negating effects of heat it is beyond the scope of this review.

Whole body cryotherapy

No articles involving WBC were included in this review due to the lack of literature with a large enough cohort. Due to this, no conclusion can be made in this review to advocate for or against this method of CT after exercise. Accordingly, a recent Cochrane review by Costello *et al*¹⁴ stated that based on the available evidence they could not advocate for WBC as a recovery method. However, it is important to note that there is no evidence of adverse events with WBC, therefore, we cannot recommend against its use. Future studies should focus on large cohorts in order to obtain good evidence in regard to this method of CT.

Limitations

As with all systematic reviews, this study was limited by the available literature. Despite the high levels of evidence (1 and 2) of the published studies involving CT in athletes following exercise, there was no homogeneous method of evaluating recovery following exercise. This led to an inability to statistically compare outcome variables. Furthermore, the quality of evidence obtained was shown to be of low quality, despite it being level 1 or 2 evidence. Another limitation is the variability in exercise protocols, which prevented direct comparison of

the included studies because each protocol may have prompted differing amounts of exercise-induced soft tissue damage.

CONCLUSION

To our knowledge, this is the first systematic review to evaluate the effect of all different types of CT on recovery in athletes immediately following and 24 hours after CT. Unfortunately, the literature consists of outcomes and protocols that vary widely, therefore, definitive conclusions are not easily made. We can conclude that the duration of ice CT has a direct impact on outcomes, and therefore recommend only using prolonged icing (>10 min) for pure hypoalgesia. CWI therapy may facilitate recovery and alleviate muscle soreness within the first 24 hours following activity; and we advocate for a protocol of immersion time of 11–15 min in 11°C–15°C (52°F–59°F) water. However, athletes who do not have to compete on a daily basis could see more benefit.

Future research

Further research in this area should focus on establishing a protocol and fixed outcome variables that allow the assessment of recovery immediately following exercise and after 24 hours. Additionally, the large variety of protocols should be subdivided to evaluate specific activities. This will allow evaluation of the soft tissue damage that occurs with varying exercises. Furthermore, future research in this area should consist of high-quality randomised controlled trials of parallel groups with group concealment and sufficient sample sizes to obtain satisfactory power.

Contributors MF and CM significantly contributed to the study conception and design. AHJ and TDL performed data extraction, analysis and interpretation. AHJ and TDL drafted the original manuscript that then underwent critical revisions by MF and CM. All authors gave final approval of this version of the manuscript to be submitted for publication.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

- Swenson C, Swärd L, Karlsson J. Cryotherapy in sports medicine. *Scand J Med Sci Sports* 1996;6:193–200.
- Bleakley C, McDonough S, MacAuley D. The use of ice in the treatment of acute soft tissue injury: a systematic review of randomized controlled trials. *Am J Sports Med* 2004;32:251–61.
- Meeusen R, Lievens P. The use of cryotherapy in sports injuries. *Sports Med* 1986;3:398–414.
- MacAuley DC. Ice therapy: how good is the evidence? *Int J Sports Med* 2001;22:379–84.
- Banfi G, Lombardi G, Colombini A, et al. Whole-body cryotherapy in athletes. *Sports Med* 2010;40:509–17.
- Collins NC. Is ice right? Does cryotherapy improve outcome for acute soft tissue injury? *Emerg Med J* 2008;25:65–8.
- Knight K. Effects of hypothermia on inflammation and swelling. *Athletic Training* 1976;11:7–10.
- Drinkwater E. Effects of peripheral cooling on characteristics of local muscle. *Med Sci Sports Exerc* 2008;40:174–88.
- Lee H, Natsui H, Akimoto T, et al. Effects of cryotherapy after contusion using real-time intravital microscopy. *Med Sci Sports Exerc* 2005;37:1093–8.
- Ohkoshi Y, Ohkoshi M, Nagasaki S, et al. The effect of cryotherapy on intraarticular temperature and postoperative care after anterior cruciate ligament reconstruction. *Am J Sports Med* 1999;27:357–62.
- Deal DN, Tipton J, Rosencrance E, et al. Ice reduces edema. A study of microvascular permeability in rats. *J Bone Joint Surg Am* 2002;84-A:1573–8.
- Merrick MA, Rankin JM, Andres FA, et al. A preliminary examination of cryotherapy and secondary injury in skeletal muscle. *Med Sci Sports Exerc* 1999;31:1516–21.
- Knight KL. Cold as a modifier of sports-induced inflammation. Leadbetter WB, ed. *Sports-induced inflammation: clinical and basic science concepts*, Park Ridge, Ill, American Academy of Orthopaedic Surgeons, 1990:463–77.
- Costello JT, Baker PR, Minett GM, et al. Cochrane review: Whole-body cryotherapy (extreme cold air exposure) for preventing and treating muscle soreness after exercise in adults. *J Evid Based Med* 2016;9:43–4.
- Bleakley C, McDonough S, Gardner E, et al. Cold-water immersion (cryotherapy) for preventing and treating muscle soreness after exercise. *Cochrane Database Syst Rev* 2012;2:CD008262.
- Higgins TR, Greene DA, Baker MK. Effects of cold water immersion and contrast water therapy for recovery from team sport: A systematic review and meta-analysis. *J Strength Cond Res* 2017;31:1443–1460.
- Pritchard KA, Saliba SA. Should athletes return to activity after cryotherapy? *J Athl Train* 2014;49:95–6.
- Bleakley CM, Bieuzen F, Davison GW, et al. Whole-body cryotherapy: empirical evidence and theoretical perspectives. *Open Access J Sports Med* 2014;5:25–36.
- Bleakley CM, Costello JT, Glasgow PD. Should athletes return to sport after applying ice? A systematic review of the effect of local cooling on functional performance. *Sports Med* 2012;42:69–87.
- Sarver DC, Sugg KB, Disser NP, et al. Local cryotherapy minimally impacts the metabolome and transcriptome of human skeletal muscle. *Sci Rep* 2017;7:2423.
- Costello JT, Baker PR, Minett GM, et al. Whole-body cryotherapy (extreme cold air exposure) for preventing and treating muscle soreness after exercise in adults. *Cochrane Database Syst Rev* 2015;9:CD010789.
- White GE, Wells GD. Cold-water immersion and other forms of cryotherapy: physiological changes potentially affecting recovery from high-intensity exercise. *Extrem Physiol Med* 2013;2:26.
- Costello JT, Algar LA, Donnelly AE. Effects of whole-body cryotherapy (-110 °C) on proprioception and indices of muscle damage. *Scand J Med Sci Sports* 2012;22:190–8.
- Hauswirth C, Schaal K, Le Meur Y, et al. Parasympathetic activity and blood catecholamine responses following a single partial-body cryostimulation and a whole-body cryostimulation. *PLoS One* 2013;8:e72658.
- Imai K, Sato H, Hori M, et al. Vagally mediated heart rate recovery after exercise is accelerated in athletes but blunted in patients with chronic heart failure. *J Am Coll Cardiol* 1994;24:1529–35.
- MacAuley D. Do textbooks agree on their advice on ice? *Clin J Sport Med* 2001;11:67–72.
- Cuttell S, Hammond L, Langdon D, et al. Individualising the exposure of -110°C whole body cryotherapy: The effects of sex and body composition. *J Therm Biol* 2017;65:41–7.
- Howatson G, Gaze D, van Someren KA. The efficacy of ice massage in the treatment of exercise-induced muscle damage. *Scand J Med Sci Sports* 2005;15:416–22.
- Yackzan L, Adams C, Francis KT. The effects of ice massage on delayed muscle soreness. *Am J Sports Med* 1984;12:159–65.
- Isabell WK. *The effects of ice massage, ice massage with exercise, and exercise on the prevention and treatment of delayed muscle soreness*: Eugene, Ore; Microform Publications, Int'l Institute for Sport and Human Performance, Univ. of Oregon, 1994.
- Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Int J Surg* 2010;8:336–41.
- Burns PB, Rohrich RJ, Chung KC. The levels of evidence and their role in evidence-based medicine. *Plast Reconstr Surg* 2011;128:305–10.
- Slim K, Nini E, Forestier D, et al. Methodological index for non-randomized studies (MINORS): development and validation of a new instrument. *ANZ J Surg* 2003;73:712–6.
- Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: Is blinding necessary? *Control Clin Trials* 1996;17:1–12.
- Ruiz DH, Myrer JW, Durrant E, et al. Cryotherapy and sequential exercise bouts following cryotherapy on concentric and eccentric strength in the quadriceps. *J Athl Train* 1993;28:320–3.
- Verducci FM. Interval cryotherapy and fatigue in university baseball pitchers. *Res Q Exerc Sport* 2001;72:280–7.
- 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;43:356–66.
- Yanagisawa O, Miyanaga Y, Shiraki H, et al. The effects of various therapeutic measures on shoulder strength and muscle soreness after baseball pitching. *J Sports Med Phys Fitness* 2003;43:189–201.
- Fischer J, Van Lunen BL, Branch JD, et al. Functional performance following an ice bag application to the hamstrings. *J Strength Cond Res* 2009;23:44–50.
- Anaya-Terroba L, Arroyo-Morales M, Fernández-de-Las-Peñas C, et al. Effects of ice massage on pressure pain thresholds and electromyography activity postexercise: a randomized controlled crossover study. *J Manipulative Physiol Ther* 2010;33:212–9.
- Pointon M, Duffield R, Cannon J, et al. Cold application for neuromuscular recovery following intense lower-body exercise. *Eur J Appl Physiol* 2011;111:2977–86.
- Behringer M, Jedlicka D, Mester J. Effects of lymphatic drainage and cryotherapy on indirect markers of muscle damage. *J Sports Med Phys Fitness* 2018;58:903–9.
- Algafly AA, George KP. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. *Br J Sports Med* 2007;41:365–9.
- Lee M, Kim S, Choi H-M, et al. Ankle or knee joint cooling alters countermovement but not squat jump height in healthy collegiate athletes. *Isokinet Exerc Sci* 2017;25:1–8.
- Doeringer JR, Colas M, Peacock C, et al. The effects of postexercise cooling on muscle performance and soreness perception. *International Journal of Athletic Therapy and Training* 2018;23:73–6.
- Ascensão A, Leite M, Rebelo AN, et al. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *J Sports Sci* 2011;29:217–25.
- Elias GP, Wyckelsma VL, Varley MC, et al. Effectiveness of water immersion on postmatch recovery in elite professional footballers. *Int J Sports Physiol Perform* 2013;8:243–53.
- Webb NP, Harris NK, Cronin JB, et al. The relative efficacy of three recovery modalities after professional rugby league matches. *J Strength Cond Res* 2013;27:2449–55.
- Fonseca LB, Brito CJ, Silva RJS, et al. Use of cold-water immersion to reduce muscle damage and delayed-onset muscle soreness and preserve muscle power in jiu-jitsu athletes. *J Athl Train* 2016;51:540–9.
- Verducci FM. Interval cryotherapy and increased work, velocity and power - abstract: In. *Fifth IOC World Congress on Sport Sciences: book of abstracts*, Canberra, Sports Medicine Australia, 1999:154.
- Bishop SH, Herron RL, Ryan GA, et al. The Effect of Intermittent Arm and Shoulder Cooling on Baseball Pitching Velocity. *J Strength Cond Res* 2016;30:1027–32.
- de Paiva PRV, Tomazoni SS, Johnson DS, et al. Photobiomodulation therapy (PBMT) and/or cryotherapy in skeletal muscle restitution, what is better? A randomized, double-blinded, placebo-controlled clinical trial. *Lasers Med Sci* 2016;31:1925–33.
- Machado AF, Ferreira PH, Micheletti JK, et al. Can Water Temperature and Immersion Time Influence the Effect of Cold Water Immersion on Muscle Soreness? A Systematic Review and Meta-Analysis. *Sports Medicine* 2016;46:503–14.
- Paddon-Jones D, Quigley B. Effect of cryotherapy on muscle soreness and strength following eccentric exercise. *Int J Sports Med* 1997;18:588–90.
- Vanderlei FM, de Albuquerque MC, de Almeida AC, et al. Post-exercise recovery of biological, clinical and metabolic variables after different temperatures and durations of cold water immersion: a randomized clinical trial. *J Sports Med Phys Fitness* 2017;57:1267–75.
- Enwemeka CS, Allen C, Avila P, et al. Soft tissue thermodynamics before, during, and after cold pack therapy. *Medicine & Science in Sports & Exercise* 2002;34:45–50.
- Hing WA, White SG, Bouaaphone A, et al. Contrast therapy—A systematic review. *Physical Therapy in Sport* 2008;9:148–61.
- De Nardi M, La Torre A, Barassi A, et al. Effects of cold-water immersion and contrast-water therapy after training in young soccer players. *J Sports Med Phys Fitness* 2011;51:609–15.