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The effects of hydrotherapy and cryotherapy on recovery from acute post-exercise induced muscle damage—a network meta-analysis

Ruohan Chen[1], Xiaopeng Ma[2], Xiaoman Ma[3*] and Chenmin Cui[4]

Abstract

Background This systematic review and network meta-analysis assessed via direct and indirect comparisons the recovery effects of hydrotherapy and cold therapy at different temperatures on exercise induced muscle damage.

Methods Five databases were searched in English and Chinese. The included studies included exercise interventions such as resistance training, high-intensity interval training, and ball games, which the authors were able to define as activities that induce the appearance of EIMD. The included RCTs were analyzed using the Cochrane Risk of Bias tool. Eligible studies were included and and two independent review authors extracted data. Frequentist network meta-analytical approaches were calculated based on standardized mean difference (SMD) using random effects models. The effectiveness of each intervention was ranked and the optimal intervention was determined using the surface under the cumulative ranking curve (SUCRA) indicator.

Results 57 studies with 1220 healthy participants were included, and four interventions were examined: Cold Water Immersion (CWI), Contrast Water Therapy (CWT), Thermoneutral or Hot Water Immersion (TWI/HWI), and Cryotherapy(CRYO). According to network meta-analysis, Contrast Water Immersion (SUCRA: 79.9%)is most effective in recovering the biochemical marker Creatine Kinase. Cryotherapy (SUCRA: 88.3%) works best to relieve Delayed Onset Muscle Soreness. In the recovery of Jump Ability, cryotherapy (SUCRA: 83.7%) still ranks the highest.

Conclusion We found that CWT was the best for recovering biochemical markers CK, and CRYO was best for muscle soreness and neuromuscular recovery. In clinical practice, we recommend the use of CWI and CRYO for reducing EIMD.

Systematic Review Registration [PROSPERO], identifier [CRD42023396067].

Keywords Hydrotherapy, Cold water immersion, Contrast water immersion, Cryotherapy, Post-exercise muscle damage, Recovery

*Correspondence:
Xiaoman Ma
ma_123789@126.com
[1]Department of Physical Education, Undergraduate College, University of Science and Technology of China, Hefei, Anhui 230026, China
[2]School of Sports Medicine and Physical Therapy, Beijing Sport University, Beijing, China
[3]China Basketball College, Beijing Sport University, Beijing, China
[4]Beijing Sport University, Beijing, China

Introduction

Exercise-induced muscle damage (EIMD) is characterized by symptoms that appear immediately after acute after the initial exercise bout. and results in pain, soreness, inflammation, and reduced muscle function [1]. EIMD is associated with deterioration of muscle strength, DOMS, edema, increased body temperature, and leakage of muscle protein into circulation [2]. Furthermore, The increase in muscle function impairment and muscle soreness associated with EIDM has a significant impact on athletes. Moreover, Muscle aches and discomfort caused by EIMD can be present increasing gradually after 12–72 h of exercise, peaking in 24–72 h, and then gradually weakening to subsiding in 5–7 days [3] However, the appearance of this soreness can have a significant impact on sports performance, which is not conducive to the continuity of athletes' sports and even affects the quality of life [4, 5].

There are many studies and elaborations on the mechanism of EIMD and recovery measures, but there still needs to be a unified conclusion; with the continuous advancement of research, some of the tools leading to EIMD are also widely recognized. For example, neurotransmitter regulation is the idea that serotonin levels are significantly lower than other neurotransmitters between 3 and 24 h after exercise exhaustion and that recovery is slow. Low serotonin levels in the spinal cord lead to decreased motor neuron excitability, which promotes EIMD [6] In addition, some scholars believe that the metabolism of skeletal muscle cells directly affects the occurrence of EIMD [7]Therefore, based on these theoretical mechanisms, there are various ways to promote recovery from EIMD, including hydrotherapy, stretching, massage, active recovery, acupuncture, cryotherapy, nonsteroidal anti-inflammatory drugs (NSAIDs), compression garments, and other methods [8–11]These therapies help promote the recovery of muscle function, reduce inflammation, and reduce symptoms of delayed onset muscle soreness. Hydrotherapy and cryotherapy are widely popular, and more and more athletes will choose these two intervention methods after training to help recover from fatigue. Hydrotherapy refers to the immersion of all or part of the body in water by participants after exercise, which can be divided into different intervention programs according to different water temperatures. Cryotherapy refers to the treatment of EIDM with cold as the main application. Although cryotherapy and cold water immersion that belongs to hydrotherapy are cold therapy, the temperature of cryotherapy is much lower than that of CWI and the duration of the intervention is shorter. These two methods have also been shown in previous studies to be beneficial in treating post-exercise injuries and soreness [12].

According to the different water temperatures, hydrotherapy is divided into four types of water immersion to restore exercise capacity, including CWI(Cold Water Immersion Therapy) < 20 °C, CWT(Contrast Water Immersion)alternating CWI and HWI, HWI(Hot Water Immersion) > 36 °C, and TWI(Thermoneutral Water Immersion)20 to 36 °C. Previous studies have suggested that all four temperatures are effective in promoting EIMD. CWI can reduce cell swelling, and tissue metabolism, and minimize pain, swelling, and risk of injury. HWI can boost tissue metabolism, promote circulation, and reduce pain [13]. CWT can reduce the core temperature to a steady state or below steady state after exercise which is the temperature at rest, thereby promoting recovery [14–17].

CRYO(Cryotherapy) mainly includes WBC(whole-body cryotherapy), PBC(partial-body cryotherapy), and air pulse cryotherapy, which refers to a method of restoring or treating sports injuries by physical means such as ice or evaporative refrigerant in an environment of 0 °C or below [18] The temperature of treatment is usually Below −30 degrees. This method can rapidly lower the temperature of the tissue and reduce the inflammatory response caused by acute injury [19]. thereby accelerates the recovery of muscle damage, and promotes the recovery of sports performance [20].

Although hydrotherapy and cryotherapy are beneficial for exercise fatigue recovery, there is currently controversy about the most effective way to reduce exercise fatigue. In previous studies, meta-analyses of delayed onset muscle soreness with cold and heat measures were conducted, but only comparative analyses of pain outcomes were conducted [21] However, biochemical indicators and neuromuscular performance indicators are essential outcomes for measuring exercise fatigue, so the purpose of this study is to summarize existing studies on hydrotherapy and cryotherapy, rank their effects by different outcome measures, and conduct a comprehensive analysis to find the best intervention plan and provide a reference for athletes to select appropriate recovery measures.

Materials and methods

This systematic review was registered with PROSPERO (CRD42023396067), and the protocol was published in a peer-reviewed journal. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Network Meta-Analyses (PRISMA NMA) for our study. This section refers to the methods section of published Meta-Analysis articles [22, 23].

Search strategy

The researchers in this paper searched five electronic databases (PubMed, EMBASE, Cochrane Central

Register of Controlled Trials, Web of Science, and CNKI) from 2002 to 2023. The search strategy was constructed around the PICOS tool: (P) Population: Healthy people; (I) Intervention: CWI; CWT; HWI/TWI; CRYO. (C) Comparator: control group with passive recovery group without any intervention; (O) Outcomes: CK (Creatine kinase) DOMS (Delayed onset muscle aches) Jump ability (Countermovement jump or Squats jump). (S) Study type: RCTs. The detailed search strategy is shown in Table 1. (PubMed is used as an example)

Inclusion criteria

(1) the study design must have been an RCT. (2) Participants should be healthy men or women with no history of recent illness or other diseases. (3) A regimen of using one of CWI, CWT, HWI/TWI, CRYO immediately after a single vigorous exercise session, which the authors define as a bout of exercise that causes muscle damage and was a study of the effects of a single intervention treatment. (4) Outcome indicators including at least one of the following: DOMS, CK, and Jump Ability. (5) Outcome measures were selected within 48 h. (6) the studies had to be written in English.

Exclusion criteria

(1) Combination therapy was used in the study that could confound the outcome of the intervention (e.g., CWI combined with compression garments, CWT combined with positive recovery, CON combined with nutritional supplements) (2) The training program is long-term. (3) More data was needed for analysis, or they were excluded if the data were presented in formats such as papers or conference abstracts.

Study selection

Two researchers screened and excluded relevant studies using the literature management software Zotero, screening the titles of replicates, non-randomized controlled trials, review papers, conference papers, protocols, and correspondence. The abstract was then read by two researchers, identifying the studies to be included and excluding them. Finally, the two researchers read the remaining literature in its entirety and further determined whether the literature was eligible for criterion. In this process, the two researchers independently filtered the literature and finally compared the remaining literature. If there is the same opinion, it is eventually included; If there is a difference of opinion, it is discussed and resolved by a third researcher.

Table 1 Search strategy

Search level	Search terms with Boolean operators
Search #1	"Hydrotherapy"OR "Water immersion" OR "Cold water immersion" OR "Hot water immersion"OR "contrast water therapy"OR "contrast water immersion"OR "thermoneutral water immersion" OR "Heat Therapies" OR "Cold Therapies"OR "Cryotherapy"OR "hydrotherapy" OR "thermal therapy"
Search #2	"Muscle Fatigue" OR" Exercise-induced Muscle Damage " OR "EIMD""exhaustion "OR "Exercise Performance" OR "Delayed onset muscle soreness" OR "Exercise fatigue" OR "DOMS" OR "training stress" OR "muscle ache" OR "Exercise Performance"
Search #3	"randomized controlled trial" OR "randomized"
Search #4	#1 AND #2 AND #3

Data extraction

A Six-item, standardized, and pre-selected data extraction form was used to record data for inclusion in the study under the following headings: (1) author, (2) year of publication, (3) country, (4) Characteristics of a subject (subject, age, and Profession) (5) intervention(6) Outcome measures. (7) Time of measures.

Risk of bias in individual studies

Two researchers independently assessed the risk of bias (ROB) using the Cochrane Handbook version 5.1.0 tool for assessing ROB in RCTs. Considering the characteristics of exercise intervention, it was impossible to blind the participants in the included studies. Thus, we only evaluated the other six categories of risk bias, which included (1) randomized sequence generation, (2) treatment allocation concealment, blinding of (3) participants and (4) personnel, (5) incomplete outcome data, (6) selective reporting and (7) other sources of bias [16].

Data analysis

All studies discerned pre- and post-intervention follow-up for each outcome and calculated the mean difference between post-exercise and pre-exercise (baseline) change. Standardized mean difference (SMD) (different metrics are used across studies) and 95% confidence interval (95% CI) were used to assess the effects of various interventions on CK, DOMS, and JUMP. Respectively. If a study did not report an endpoint's mean or SD, it was calculated from the corresponding median, range, or interquartile range.

Network meta-analyses for the primary outcomes were conducted based on the frequentist framework [24, 25] using Stata software (Version 17.0; Stata Corp, College Station, TX, USA) [26]. A visualization tool was used for the graphical representation of the network geometry. The network plot consisted of nodes and edges representing the exercise modes and the number of allocated participants in that intervention. In contrast, the number of studies assessing a comparison was related to the size of the corresponding edge. For every outcome, the role of the direct and indirect evidence in the network summary was determined. Once all pairwise summary effects and variances were calculated, a weighted squares approach was used to estimate the contribution plot [24, 27]. Inconsistency test was evaluated using the loop-specific method, node-splitting, and global inconsistency; among them, the node-splitting and loop-specific process was a local analysis (between two comparisons per item), indirect and direct comparison Discrepancies. The SD of the heterogeneity for each pairwise comparison (Tau)was also provided. If both assumptions were satisfied, a consistency model was applied. Potential intervention effects were ranked using the surface under the cumulative ranking curve (SUCRA). Calculate the order of effects for each arm. The higher the SUCRA value, the better the rating of the Network Intervention (SUCRA). A SUCRA value of 100% indicates that this type of exercise intervention is most effective in the network, while a value of 0 indicates the least effective. Web funnel charts were used for different outcome measures to determine whether articles were biased [28].

Results

Study and identification and selection

We searched electronic databases for a total of 1230 documents based on search terms, and another 31 papers were hand-searched. After removing duplicate records, the remaining 727 documents were read, and titles and abstracts were obtained, again excluding 487 documents. The remaining 240 were read in total, 175 were again excluded as ineligible (Fig. 1 for details), and the remaining 57 were included in this study. This is shown in Fig. 1.

Quality assessment of the included studies

Regarding the random sequence generation and treatment allocation concealment, two studies were judged to be at high risk because they did not state whether the allocation was randomized. Regarding incomplete outcome data, two studies were at high risk due to a large proportion of subject attrition, resulting in an imbalance in the number of missing people between groups. Treatment allocation concealment, In terms of assessment of blinding of participants and personnel. Only three of these studies achieved simultaneous blinding of subjects and measures. Still, as the intervention in these studies was exercise, it was challenging to blind subjects and measurers as both the patients and their relatives had to sign an informed consent form before the experiment was conducted. Specific details will be presented in Figure S1 and Figure S2.

Characteristics of the included studies

We included studies from 57 randomized controlled trials with 1220 participants. Interventions in the control group included CWI [19, 29–71](44studies), CWT [30, 31, 35, 41, 42, 49, 50, 53, 54, 72–75](13 studies), HWI [30] (1 study), TWI [19, 29, 42, 51, 62, 69](6 studies), and CRYO [37, 39, 68, 70, 71, 76–83](14 studies), Due to the small number of studies on HWI and TWI, both treatment options are heat therapy. Therefore, the two interventions were combined for analysis. Fifty studies reported DOMS as an outcome indicator; 36 said CK as an outcome indicator, and 31 said Jump ability as an outcome indicator. The characteristics of the included studies are shown in Table 2.

Network meta-analysis

The full NMA figure will be shown in Fig. 2.

CK

All P-values for indirect and direct comparisons between all studies were tested for consistency and inconsistency, and all p-values were more significant than 0.05, indicatng that the effect of consistency between studies was acceptable. Details will be shown in Table S1.

The results of the network meta-analysis showed that, relative to the CON(control group), CWI [SMD=-0.37, 95% CI=(-0.59,-0.15)], CWT [SMD=-0.45,95% CI= (-0.80,-0.10)], HWI/TWI [SMD=0.01,95% CI=(-0.44,0.46)] and CRYO [SMD=-0.40,95% CI=(-0.86,0.05)] were superior to the control group in reducing CK; The probability ranking of the different recovery interventions in terms of lowering CK scores was ranked first in the SUCRA for CWT (SUCRA: 79.9% as shown in Fig. 3. A comparison between the two different interventions will be shown in Fig. 4.

DOMS

All *P*-values for indirect and direct comparisons between all studies were tested for consistency and inconsistency, and most *P*-values were greater than 0.05, indicating that the effect of consistency between studies was acceptable. Details will be shown in Table S2.

The results of the Network meta-analysis showed that relative to the control group's routine measures, CWI [SMD=-0.64 95% CI = (-0.94,-0.35)], CWT [SMD=-0.52,95% CI =(-0.98,-0.05)], CRYO [SMD=-0.81, 95% CI = (-1.27,-0.35)] were superior to the CON in reducing DOMS indicators. However, HWI/TWI [SMD=0.13, 95% CI =(-0.55,0.80)] is less effective than CON in reducing DOMS. The probability ranking of the different recovery interventions for reducing DOMS scores was ranked first in the SUCRA for CRYO (SUCRA: 88.3%, as shown in Fig. 3). A comparison between the two different interventions will be shown in Fig. 4.

JUMP

All P-values for indirect and direct comparisons between all studies were tested for consistency and inconsistency, and all P-values were more significant than 0.05,

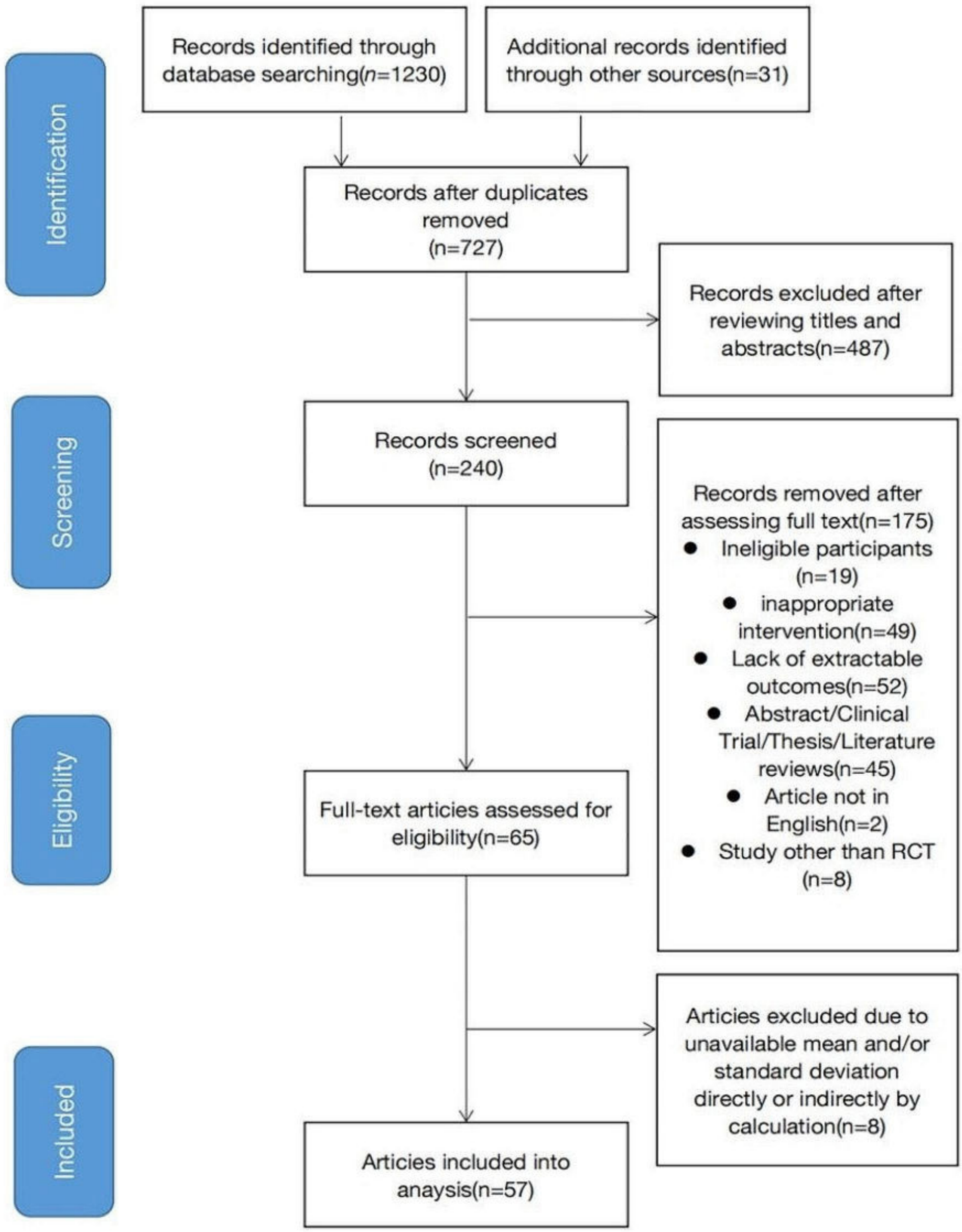

Fig. 1 PRISMA flow diagram detailing the inclusion of papers throughout the search strategy. *N* Number 57 studies that met the inclusion criteria were included in this network meta-analysis (NMA). *RCT* randomized controlled trial

Table 2 Characteristics of the included studies

Study	Country	Characteristics of subject			Interventions	Outcome measures	Time of measures
		Subject (N,sex)	Age mean(sd)	Profession			
Bouchiba et.al [29]	Tunisia	12 M	22.9(0.9)	Athletes	CWI TWI	CK JUMP	48 H
Horgan et al. [30]	Australia	18 M	19.9(3.4)	Athletes	CWI CWT HWI CON	DOMS CK	38 H
Glasgow et al. [31]	Newtownabbey	32 M 18 F	18	Non-athletes	CWI CWT CON	DOMS CK	48 H
Getto et al. [32]	US	13 M 10 F	—	Athletes	CWI CON	DOMS JUMP	24 H
Machado et al. [33]	Brazil	40 M	20.6(2.2)	Non-athletes	CWI CON	DOMS CK	48 H
Ascensaoa et al. [19]	Portugal	20 F	18.3(0.8)	Non-athletes	CWI TWI	DOMS CK JUMP	48 H
Leeder et al. [34]	UK	16 M	21 (3)	Athletes	CWI CON	DOMS CK JUMP	48 H
Higgins et al. [35]	Australia	24 M	19.5 (0.8)	Athletes	CWI CWT CON	DOMS JUMP	48 H
Siqueira et al. [36]	Brazil	29 M	20.2(1.42)	Non-athletes	CWI CON	DOMS CK JUMP	48 H
Hohenauer et al. [37]	Switzerland	18 F	22.5(2.7)	Non-athletes	CWI CRYO CON	DOMS JUMP	48 H
Coelho et al. [38]	Brazil	17-	21.7(3.28)	Athletes	CWI CON	DOMS CK JUMP	48 H
Wilson et al. [39]	UK	31 M	37.7(8.9)	Athletes	CWI CRYO	DOMS CK	48 H
Hartmann et al. [40]	Brasil	19 F	25.2 (3.6)	Athletes	CWI CON	DOMS CMJ JUMP	48 H
Elias et al. [41]	Australia	24 M	19.9(2.8)	Athletes	CWI CWT CON	DOMS JUMP	48 H
Pournot et al. [42]	France	32 M	21.5(4.6)	Athletes	CWI CWT TWI CON	DOMS CK JUMP	24 H
Rupp et al. [43]	US	13 M 9 F	19.8(1.1)	Athletes	CWI CON	JUMP	48 H
Vaile et al. [72]	Australia	4 M 9 F	26.2 (5.8)	Athletes	CWT CON	DOMS CK	48 H
Vieira et al. [44]	Brazil	28 M	20.2(2.12)	Non-athletes	CWI CON	DOMS CK JUMP	48 H
Takeda et al. [45]	Japan	20 M	20.3(0.6)	Athletes	CWI CON	CK JUMP	24 H
Kositsky et al. [46]	Finland	10 M	18.9(0.87)	Athletes	CWI CON	DOMS CK JUMP	48 H
Barber et al. [47]	UK	16 M	20(1.2)	Athletes	CWI CON	DOMS CK JUMP	48 H
Pointon et al. [48]	Australia	10 M	19.9(1.1)	Athletes	CWI CON	CK	24 H
Ingram et al. [49]	Australia	11 M	27.5(6.0)	Non-athletes	CWI CWT CON	DOMS CK	48 H
Elias et al. [50]	Australia	14 M	20.9(3.3)	Athletes	CWI CWT CON	DOMS CMJ	48 H
Bouzid et al. [51]	Tunisia	8-	19.63(0.74)	Athletes	CWI TWI	DOMS CK JUMP	48 H
Moreira et al. [52]	Brazil	10 M	24(3)	Athletes	CWI CON	DOMS JUMP	24 H
Crowther et al. [53]	Australia	29 M	27(6)	Non-athletes	CWI CWT CON	DOMS JUMP	48 H
Dawson et al. [73]	Australia	17-	24.2(2.9)	Athletes	CWT CON	DOMS CK JUMP	48 H
Robey et al. [74]	Australia	8 M 6 F	20.65(2.96)	Athletes	CWT CON	DOMS CK	48 H
French et al. [75]	UK	16 M	24.12(3.2)	Non-athletes	CWT CON	DOMS CK JUMP	48 H
Qu et al. [54]	China	12 M	21.00(0.95)	Athletes	CWI CWT CON	DOMS CK JUMP	48 H
Amir et al. [55]	Malaysia	16 M	21.6(2.3)	Non-athletes	CWI CON	DOMS CK	48 H
Goodall et al. [56]	UK	18 M	24(5)	Non-athletes	CWI CON	DOMS CK	48 H
Howatson et al. [57]	UK	16 M	23(3)	Non-athletes	CWI CON	DOMS	48 H
Jakeman et al. [58]	UK	18f	19.9(0.97)	Athletes	CWI CON	DOMS CK	48 H
Braulio et al. [59]	UK	26f	21.8(2.8)	Non-athletes	CWI CON	JUMP	48 H
Anderson et al. [60]	UK	9 M	24(2)	Athletes	CWI CON	DOMS CK	48 H
Bailey et al. [61]	UK	20 M	22.3(3.3)	Non-athletes	CWI CON	DOMS CK	48 H
Dantas et al. [62]	Brazil	20 M	30.64(5.6)	Non-athletes	CWI TWI CON	DOMS CK	24 H
Fonseca et al. [63]	Brazil	8 M	24.0(3.6)	Athletes	CWI CON	DOMS CK JUMP	48 H
Lindsay et al. [64]	US	15 M	28.3(5.7)	Athletes	CWI CON	DOMS JUMP	24 H
Minett et al. [65]	Australia	9 M	21(2)	Athletes	CWI CON	DOMS CK	24 H

Table 2 (continued)

Study	Country	Characteristics of subject			Interventions	Outcome measures	Time of measures
		Subject (N,sex)	Age mean(sd)	Profession			
Tabben et al. [66]	France	12 M	26.5(5.0)	Athletes	CWI CON	CK JUMP	24 h
Wiewelhove et al. [67]	Germany	23 M	30.5(10.9)	Athletes	CWI CON	DOMS CK JUMP	24 h
Hohenauer et al. [68]	Switzerland	19 M	25.9(4.4)	Non-athletes	CWI CRYO	DOMS JUMP	48 H
Doungkulsa et al. [76]	Thailand	32 M	21.31(1.03)	Non-athletes	CRYO CON	DOMS	48 H
Guilhem et al. [18]	France	24 M	24.55(1.39)	Non-athletes	CRYO CON	DOMS	48 H
Costello et al. [77]	Ireland	12 F 24 M	20.8(1.2)	Non-athletes	CRYO CON	DOMS	48 H
Fonda et al. [78]	Slovenia	11 M	26.9(3.8)	Non-athletes	CRYO CON	CK JUMP	48 H
Hausswirth et al. [79]	Spain	9-	31.8(6.5)	Athletes	CRYO CON	DOMS CK	48 H
Lima et al. [80]	Brazil	19 F	21.6(2.0)	Non-athletes	CRYO CON	DOMS	48 H
Ferreira et al. [81]	Brazil	26 M	20.2(2.5)	habitually active	CRYO CON	DOMS	48 H
Hohenauer et al. [69]	Switzerland	17 F 5 M	22.6(2)	Non-athletes	CWI TWI	DOMS JUMP	48 H
Oakley et al. [82]	Michigan	17 M 15 F	24(4.0)	Non-athletes	CRYO CON	DOMS CK	48 H
Petrofsky et al. [83]	Korea	40-	25.3(3.0)	Non-athletes	CRYO CON	DOMS	48 H
Rose et al. [70]	Australia	13 M	-	Non-athletes	CWI CRYO CON	DOMS	48 H
Haq et al. [71]	UK	33 M	37.0(13.3)	Non-athletes	CWI CRYO CON	DOMS CK	24 H

UK United Kingdom *US* United States *M* Male *F* Female – Unknown *CWI* cold water immersion *CWT* contrast water therapy *HWI /TWI* hot water immersion and thermoneutral water immersion CRYO Cryotherapy *CON* Control *CK* creatine kinase *DOMS* Delayed onset muscle aches *JUMP* jump ability *H* hours

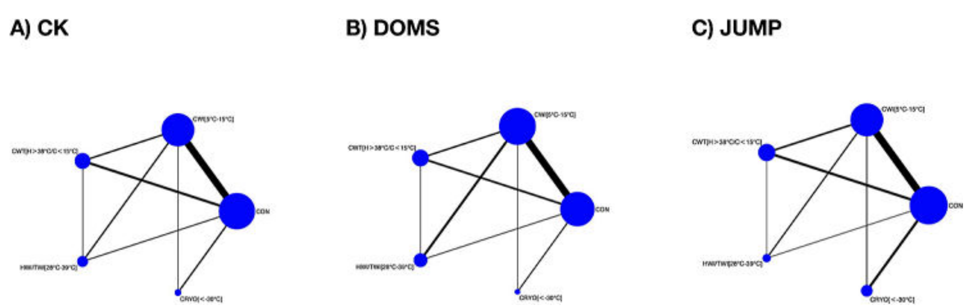

Fig. 2 Network plots of the (**A**) CK, (**B**) DOMS, and (**C**) JUMP *CWI[5°-15°]* cold water immersion *CWT[H > 38°/C < 15°]* contrast water therapy *HWI/TWI[28°-39°]* hot water immersion and thermoneutral water immersion *CRYO[<-30°]* Cryotherapy *CON* Control

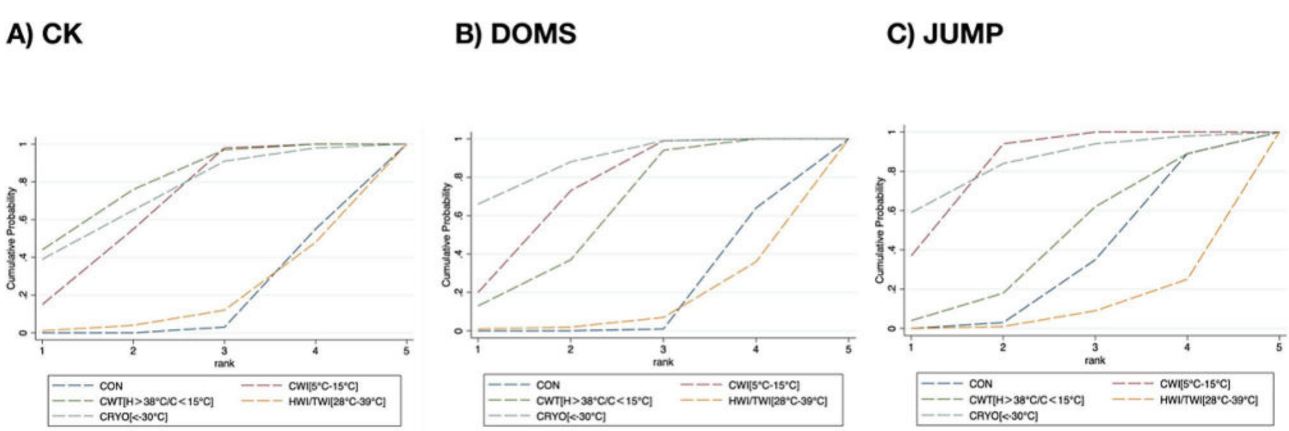

Fig. 3 SUCRA plot of the creatine kinase (**A**), Delayed Onset Muscle Soreness (**B**), and Jump Ability (**C**). *CWI[5°-15°]* cold water immersion *CWT[H > 38°/C < 15°]* contrast water therapy *HWI/TWI[28°-39°]* hot water immersion and thermoneutral water immersion *CRYO[<-30°]* Cryotherapy *CON* Control

A) CK

CWI[5℃-15℃]				
0.09 (-0.28,0.45)	CWT[H>38℃/C<15℃]			
-0.38 (-0.81,0.06)	-0.46 (-0.97,0.05)	HWI/TWI[28℃-39℃]		
0.04 (-0.44,0.52)	-0.05 (-0.62,0.52)	0.41 (-0.21,1.04)	CRYO[<-30℃]	
-0.37 (-0.59,-0.15)	**-0.45 (-0.80,-0.10)**	0.01 (-0.44,0.46)	**-0.81 (-1.27,-0.35)**	CON

B) DOMS

CWI[5℃-15℃]				
-0.13 (-0.61,0.35)	CWT[H>38℃/C<15℃]			
-0.77 (-1.42,-0.12)	-0.64 (-1.39,0.11)	HWI/TWI[28℃-39℃]		
0.17 (-0.33,0.67)	0.29 (-0.34,0.93)	**0.94 (0.14,1.73)**	CRYO[<-30℃]	
-0.64 (-0.94,-0.35)	**-0.52 (-0.98,-0.05)**	0.13 (-0.55,0.80)	**-0.81 (-1.27,-0.35)**	CON

C) JUMP

CWI[5℃-15℃]				
0.29 (-0.14,0.73)	CWT[H>38℃/C<15℃]			
0.60 (0.19,1.00)	0.30 (-0.23,0.83)	HWI/TWI[28℃-39℃]		
-0.08 (-0.64,0.48)	-0.37 (-1.06,0.31)	-0.68 (-1.35,0.00)	CRYO[<-30℃]	
0.37 (0.13,0.61)	0.08 (-0.35,0.50)	-0.23 (-0.66,0.21)	0.45 (-0.11,1.00)	CON

Fig. 4 Comparative effectiveness results for Creatine Kinase (**A**), Delayed Onset Muscle Soreness (**B**), and Jump Ability (**C**). Each cell shows an SMD with a 95%CI. *95%CI* 95% confidence interval; *SMD* standardized mean difference; *CWI[5°-15°]* cold water immersion *CWT[H > 38°/C < 15°]* contrast water therapy *HWI/TWI[28°-39°]* hot water immersion and thermoneutral water immersion *CRYO[<-30°]* Cryotherapy *CON* Control

indicating that the effect of consistency between studies was acceptable. Details will be shown in Table S3.

The results of the Network meta-analysis showed that CWI [SMD=0.37,95% CI = (0.13,0.61)], CWT [SMD=0.08,95% CI = (-0.35,0.50)], and CRYO [SMD=0.45,95% CI = (-0.11,1.00)] were superior to the CON in the recovery of jumping ability. However, the recovery effect of HWI/TWI on jumping ability could have been better than that of the control group. The probability ranking of the different recovery interventions in jump ability was ranked first by CRYO in the SUCRA (SUCRA: 83.7%, as shown in Fig. 3). A comparison between the two different interventions will be shown in Fig. 4.

Publication bias test

We constructed separate funnel plots for all outcomes to test for possible publication bias. Visual inspection of the funnel chart revealed no significant publication bias. The details are shown in Fig. 5.

Discussion

This study focused on the effects of different temperature hydrotherapy and cryotherapy interventions on fatigue recovery. A total of 57 studies, included a total of 1220 participants, including four different interventions and one control group. Among them, In our study, the temperature range included in CWI was 5°-15°, with CWT at H>38°/C<15°, TWI/HWI28°-39°, and CRYO below −30°. Through this study, we found that CWT is the best recovery intervention for recovering biochemical markers of CK. But CRYO is the best recovery intervention for delayed onset muscle aches. In terms of JUMP, CRYO is also the best recovery intervention.

We reviewed studies that assessed muscle damage and inflammation and found that exercise-induced muscle damage and inflammation were associated with changes in blood biochemistry, subjective perceptions, and muscle performance. Of these three areas, metrics such as CK、DOMS and JUMP are most commonly used to evaluate EIMD, so these three indicators are meaningful. Although other measures can also be useful for assessing muscle damage and inflammation, the scarcity of data is insufficient to support a network meta-analysis.

EIMD can cause alterations in hematogenous biomarkers, including CK, AST, myoglobin, CRP, IL-6, LDH and other indicators. with CK being one of the most common, It is also the only indicator with sufficient data to support meta-analysis, this biomarker is associated with intracellular energy production, muscle contraction, and ATP regeneration; an increase in its levels combined with slower recovery can indicate the presence of fatigue [84]. CWT after exercise may help to reduce inflammation and edema, as CWI constricts blood vessels and lymphatic vessels. At the same time, hot water immersion expands them, aiding the drainage of exudate from the extracellular fluid. Therefore, CWT can be beneficial. So, CWT can encourage blood flow by narrowing and

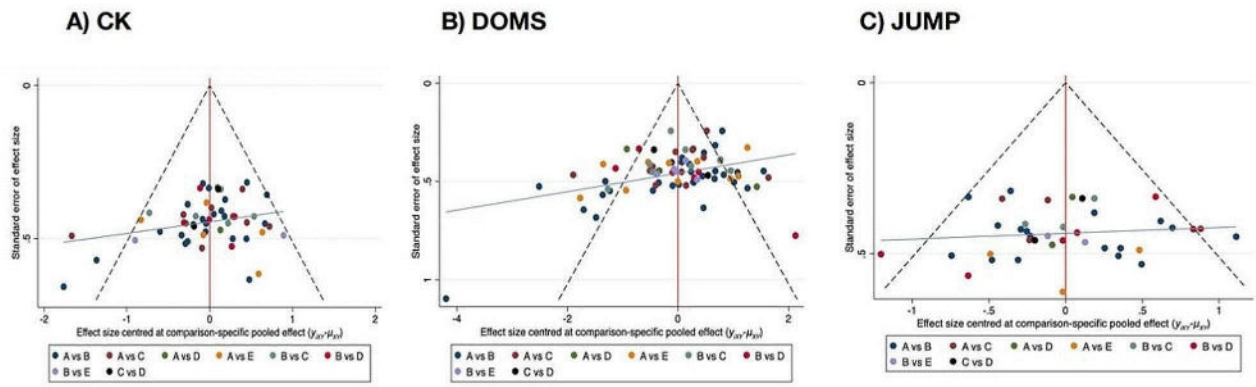

Fig. 5 Funnel plot on publication bias for Creatine Kinase (**A**), Delayed Onset Muscle Soreness (**B**), and Jump Ability (**C**). *A* Control *B* cold water immersion (5°-15°) *C* Contrast water therapy (H > 38°/C < 15°) *D* hot water immersion and thermoneutral water immersion(28°-39°) *E* Cryotherapy (<-30°)

dilating vessels, decreasing the inflammatory reaction in the area of injury, and advancing the elimination rate of CK [85] In addition, changes in water temperature have been found to cause rapid changes in muscle perfusion (the "pumping effect") that promote lactic acid and waste removal, thereby promoting recovery [86] Our study indicates that CWT has a statistically significant beneficial effect on the recovery of CK due to exercise fatigue compared to other interventions. There was a statistically significant difference compared to the control group.

In addition to changes in biochemical indicators, EIMD can also produce DOMS, This phenomenon usually appears and intensifies within 24–72 h after High-intensity training [3]. DOMS are often measured using the Visual Analogue Scale (VAS), a simple and effective tool to assess pain levels and can accurately measure sensitive changes in the patient's pain experience [87, 88] In our study, we found that except for HWI/TWI, all other therapies were significantly more effective than controls in reducing DOMS. Among them, CRYO is the most effective intervention, consistent with previous studies [21, 89] CRYO is typically exposed to frigid, dry air (<-100 °C) or Frigid air (-30 °C) and is applied topically to the skin and subcutaneous tissue by convection; due to the extremely low temperature, the CRYO is generally around in 2–5 min. It stimulates skin receptors and Sympathetic adrenergic fibers by reducing the temperature of muscles, skin, and core. It promotes local vasoconstriction, reduces local tissue metabolism and inflammation, reduces receptor sensitivity and nerve conduction velocity, and can effectively reduce muscle soreness after exercise.

With the production of EIMD, in addition to the change of biochemical indicators and the appearance of muscle soreness, it will also lead to a decline in neuromuscular performance, and jumping ability is an important indicator to evaluate neuromuscular performance, of which CMJ(countermovement jump) and SJ (Squat jump) are typical indicators for evaluating jumping ability. Studies have found that impaired neuromuscular function and neuromuscular efficiency after muscle fibre damage directly lead to a decline in CMJ scores [45] In our research, we found that most subjects had a decrease in jumping ability regardless of the intervention; in contrast, CRYO was the most effective in alleviating the decline in JUMP, and CWI and CWT were also effective in reducing the decline in jumping ability compared to the CON. We suspect this may be related to the physiological effects of temperature, where intervention at cold or extremely cold temperatures can cause local vasoconstriction, reduce fluid diffusion and vascular permeability, reduce edema formation, and thus reduce the acute inflammatory response to muscle injury. However, regardless of the effect of the intervention, the neuromuscular function had more difficulty reaching baseline levels within 48 h of exercise, which may indicate that these intervention strategies are limited in improving neuromuscular recovery before the next training session or competition.

Strengths and limitations

First, our study mainly included 57 studies with 1220 participants and had 4 interventions compared with control groups; the effects of 4 interventions were analyzed using three critical indicators to assess the recovery effect of exercise-induced muscle damage. They were Providing updated and more comprehensive evidence-based recommendations.

Secondly, our studies had some limitations, and although we tried to avoid study heterogeneity when including primary studies, for example, factors between studies, such as age, region, etc., could not be avoided. In addition, the study found that only six studies used a purely female cohort, eight used a mixed fellow, and the other studies used a purely male mate so that this review may reflect more on the effects of the four interventions on muscle damage in men.

Finally, readers should interpret the results of our study cautiously due to uncontrolled heterogeneity. In addition, future studies of women should be expanded to use female-only cohorts for muscle damage recovery and to identify appropriate recovery regimens for female athletes.

Conclusions

This review and meta-analysis identified 57 studies investigating the effects of CWI, CWT, HWI/TWI, and CRYO on physiological, sensory, and neuromuscular recovery. We found that CWT was the best for recovering biochemical markers CK, and CRYO was best for muscle soreness and neuromuscular recovery. In clinical practice, we recommend the use of CWI and CRYO for reducing EIMD. (S1) However, It is still necessary to develop a recovery plan according to the individualization of the athlete, which is currently more recommended. Future research needs to be closer to the optimal temperature and best intervention practices, depending on the participants. more high-quality literature is needed to substantiate this conclusion.

Supplementary Information

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Supplementary Material 1

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Declarations

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