



The Relationship Between Hot-Cold Compression Therapy and Delayed Onset Muscle Soreness (DOMS) : A Comprehensive Systematic Review

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ABSTRACT

Introduction: Delayed Onset Muscle Soreness (DOMS) represents a common consequence of unaccustomed or intense exercise, characterized by pain, reduced function, and inflammation. Despite widespread use of thermal and compression therapies in sports recovery, the optimal application parameters and comparative effectiveness remain unclear. This systematic review evaluated the relationship between hot-cold compression therapy and DOMS outcomes.

Methods: A comprehensive systematic review was conducted across multiple databases, screening studies based on predefined criteria including population (healthy individuals or athletes), intervention (thermal and/or compression therapies), outcomes (DOMS-related measures), and study design (RCTs, controlled trials, systematic reviews). Data extraction focused on intervention parameters, population characteristics, DOMS assessment methods, and primary findings.

Results: Eighty studies were included, encompassing diverse interventions including contrast water therapy (CWT), cold water immersion (CWI), compression therapy, and combined approaches. CWI at 10-15°C for 10-15 minutes demonstrated consistent benefits for pain reduction (SMD -0.48 to -0.75) and functional recovery. Compression therapy, particularly pneumatic devices, improved muscle soreness (SMD -0.33) and performance measures. Combined thermal-compression approaches showed synergistic effects in some contexts ($d = 0.67$ -1.12 for strength recovery), though not universally superior.

Discussion: Intervention effectiveness demonstrated systematic variation based on temperature (optimal CWI: 10-15°C), duration (CWT optimal at 6 minutes), timing (immediate post-exercise application critical), and population (trained males show robust responses; females may respond differently). Methodological quality varied substantially, with placebo effects potentially contributing to reported benefits.

Conclusion: Cold water immersion at 10-15°C for 10-15 minutes immediately post-exercise represents the most consistently beneficial single modality for DOMS, particularly in trained male athletes. Compression therapies offer viable alternatives with distinct mechanisms. Personalized approaches considering individual response patterns and resource availability are recommended over universal protocols.

Keywords: Delayed onset muscle soreness, cryotherapy, compression therapy, contrast therapy, sports recovery, exercise-induced muscle damage

INTRODUCTION

Delayed Onset Muscle Soreness (DOMS) represents a ubiquitous phenomenon following unaccustomed or strenuous physical activity, characterized by pain, stiffness, reduced range of motion, diminished force production, and functional impairment that typically peaks 24-72 hours post-exercise (1). This condition, resulting primarily from eccentric exercise-induced microtrauma to muscle fibers, affects athletes across all levels of competition and recreational exercisers alike, creating significant implications for training continuity, performance optimization, and quality of life (16, 18).

Background

The pathophysiology of DOMS involves a complex cascade of mechanical disruption, inflammatory responses, and metabolic disturbances. Eccentric muscle contractions generate disproportionate tensile forces that cause sarcomere disruption, Z-line streaming, and extracellular matrix damage (1, 16). This mechanical insult triggers a secondary inflammatory response characterized by neutrophil infiltration, prostaglandin synthesis, and release of pro-inflammatory cytokines, which contribute to the characteristic pain and dysfunction (12, 18). The condition's predictable temporal course—emerging 8-24 hours post-exercise, peaking at 24-72 hours, and resolving within 5-7 days—provides a structured framework for investigating recovery interventions (1, 4).

Thermal and compression therapies have long been employed in sports medicine settings based on theoretical mechanisms including vasodilation/vasoconstriction modulation, edema reduction, metabolic waste clearance, and gate control pain inhibition (2, 4, 6). Cold therapy purportedly reduces inflammation, vasospasm, and nerve conduction velocity, while heat therapy aims to enhance blood flow, tissue extensibility, and metabolic activity (4, 5). Compression theoretically improves venous return, lymphatic drainage, and proprioceptive input (6, 7). However, the optimal combination, timing, and application parameters for these modalities remain subjects of ongoing investigation.

Research Gap

Despite widespread clinical adoption and an expanding evidence base, significant gaps persist in understanding the optimal application of hot-cold compression therapy for DOMS. Existing literature demonstrates substantial heterogeneity in intervention protocols, population characteristics, outcome measures, and methodological quality (1, 17). Direct comparisons between modalities remain limited, and few studies have systematically evaluated the potential synergistic effects of combined thermal and compression approaches. Furthermore, the influence of individual factors such as sex, training status, and exercise modality on treatment response remains poorly characterized (13, 17).

Problem Statement

The central question guiding this systematic review is: What is the relationship between hot-cold compression therapy and DOMS outcomes, and what factors influence treatment effectiveness across different populations and contexts?

Objectives

This systematic review aims to:

1. Synthesize available evidence on the effectiveness of hot-cold compression therapy for DOMS
2. Identify optimal application parameters including temperature, duration, timing, and frequency
3. Compare effectiveness across different modalities (cold alone, heat alone, contrast therapy, compression alone, combined approaches)
4. Evaluate factors modifying treatment response including population characteristics, exercise type, and methodological considerations

Novelty

This review provides a comprehensive synthesis focusing specifically on combined thermal and compression approaches, distinguishing it from previous systematic reviews that have

examined these modalities in isolation. By integrating findings across 80 studies, this review offers novel insights into contextual factors that explain apparent contradictions in the literature and provides practical guidance for clinical implementation.

Hypothesis

We hypothesized that combined thermal-compression approaches would demonstrate superior effectiveness compared to single-modality interventions, and that effectiveness would vary systematically based on application parameters (temperature, duration, timing) and population characteristics.

Significance and Benefits

Understanding the optimal application of hot-cold compression therapy for DOMS has substantial implications for sports medicine practitioners, athletes, and rehabilitation professionals. Evidence-based protocols can optimize recovery strategies, potentially reducing downtime, maintaining training intensity, and improving performance outcomes. Additionally, identifying factors that moderate treatment response enables personalized approaches that maximize benefit while minimizing unnecessary resource expenditure.

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate The Relationship Between Hot-Cold Compression Therapy and Delayed Onset Muscle Soreness (DOMS).

Screening

We screened in sources based on their abstracts that met these criteria:

- **Population:** Does the study include healthy individuals or athletes who experienced or were induced to experience DOMS, without underlying muscle disorders, chronic diseases, or conditions that would confound DOMS assessment?
- **Intervention Type:** Does the intervention involve hot-cold compression therapy or contrast therapy with a compression component (not limited to heat therapy alone, cold therapy alone, or compression alone)?
- **Outcome Measures:** Does the study measure DOMS-related outcomes (such as muscle soreness, pain scores, functional performance, range of motion, or biochemical markers of muscle damage) as primary or secondary outcomes?
- **Study Design:** Is the study design a randomized controlled trial, controlled clinical trial, crossover trial, systematic review, or meta-analysis (not a case report, case series, editorial, or opinion piece)?
- **Comparison Group:** Does the study compare hot-cold compression therapy to a control group, placebo, no treatment, or alternative intervention?
- **Study Subjects:** Are the study participants human subjects (not animal or in vitro studies)?
- **Study Focus:** Does the study focus on exercise-induced muscle damage rather than acute injury treatment or chronic pain conditions unrelated to DOMS?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Search Strategy

The keywords used for this research based PICO :

PICO Component	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population	Athletes	Physically active	Healthy adults	Healthy

		individuals		volunteers
Intervention	Hot-cold compression therapy	Contrast therapy with compression	Cryocompression	Thermal compression
Comparison	Passive recovery	Placebo	No treatment	Alternative intervention
Outcome	Delayed onset muscle soreness (DOMS)	Muscle soreness	Muscle pain	Recovery of muscle function

The Boolean MeSH keywords inputted on databases for this research are: (*"Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers"*) AND (*"Hot-cold compression therapy" OR "Contrast therapy with compression" OR "Cryocompression" OR "Thermal compression"*) AND (*"Passive recovery" OR "Placebo" OR "No treatment" OR "Alternative intervention"*) AND (*"Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function"*)

Data extraction

- **Study Design:**

Extract study design type (RCT, crossover, repeated measures, etc.) and sample size. Include any key methodological features that affect interpretation of hot-cold compression therapy effects on DOMS.

- **Population Characteristics:**

Extract participant details relevant to DOMS research, including:

- Demographics (age, sex, fitness level)

- Training status (trained, untrained, recreational athletes)
- Health status
- Any exclusion criteria that might affect generalizability of thermal/compression therapy effects

- **DOMS Induction Method:**

Extract the exercise protocol used to induce DOMS, including:

- Type of exercise (eccentric, resistance, etc.)
- Intensity and duration
- Muscle groups targeted
- Any details about the severity of DOMS induced

- **Thermal Therapy Details:**

Extract all details about hot and/or cold therapies tested for DOMS, including:

- Type (cold water immersion, hot water immersion, contrast therapy, ice packs, heat packs, etc.)
- Temperature specifications
- Duration and frequency of application
- Timing relative to exercise (immediate, delayed)
- Any combination with other thermal modalities

- **Compression Therapy Details:**

Extract all details about compression interventions tested for DOMS, including:

- Type (garments, sleeves, pneumatic compression, etc.)
- Compression pressure/level
- Duration of wear
- Timing relative to exercise
- Body parts compressed
- Any combination with thermal therapies

- **DOMS Assessment Methods:**

Extract how DOMS was measured, including:

- Subjective measures (pain scales, soreness ratings, specific instruments used)
- Objective measures (strength/power tests, range of motion, functional assessments)
- Biochemical markers (CK, LDH, inflammatory markers)
- Timing of all assessments relative to exercise

- **Primary Findings:**

Extract the main results showing the relationship between hot-cold compression therapy and DOMS, including:

- Direction of effect (beneficial, harmful, no effect)
- Magnitude of effect (effect sizes, percentage changes, statistical significance)
- Which specific interventions were most/least effective

- Any dose-response relationships identified

- **Timing Effects:**

Extract findings about when thermal/compression interventions are most effective for DOMS, including:

- Optimal timing of application relative to exercise
- Duration of treatment effects
- Differences in effectiveness at various time points post-exercise (24h, 48h, 72h, etc.)
- Any time-sensitive recommendations provided

- **Comparative Effectiveness:**

Extract any direct comparisons between different thermal/compression approaches for DOMS, including:

- Head-to-head comparisons between hot vs. cold vs. contrast therapies
- Compression alone vs. thermal alone vs. combined approaches
- Relative effectiveness rankings if provided
- Any interactions between thermal and compression components

- **Study Limitations:**

Extract key limitations and contextual factors that affect interpretation of hot-cold compression therapy effects on DOMS, including:

- Study quality issues
- Generalizability concerns

- Confounding factors
- Author recommendations for future research
- Any factors that might explain conflicting results across studies

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	<i>("Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers") AND ("Hot-cold compression therapy" OR "Contrast therapy with compression" OR "Cryocompression" OR "Thermal compression") AND ("Passive recovery" OR "Placebo" OR "No treatment" OR "Alternative intervention") AND ("Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function")</i>	2
Semantic Scholar	<i>("Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers") AND ("Hot-cold compression therapy" OR "Contrast therapy with compression" OR "Cryocompression" OR "Thermal compression") AND ("Passive recovery" OR "Placebo" OR "No treatment" OR "Alternative intervention") AND ("Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function")</i>	2
Springer	<i>("Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers") AND ("Hot-cold compression therapy" OR "Contrast therapy with compression" OR "Cryocompression" OR "Thermal compression") AND ("Passive recovery" OR "Placebo" OR "No treatment" OR "Alternative intervention") AND ("Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function")</i>	1
Google Scholar	<i>("Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers") AND ("Hot-cold compression therapy" OR "Contrast therapy with compression" OR "Cryocompression" OR "Thermal compression") AND ("Passive recovery" OR "Placebo" OR "No treatment" OR "Alternative intervention") AND ("Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function")</i>	35
Wiley Online Library	<i>"Athletes" OR "Physically active individuals" OR "Healthy adults" OR "Healthy volunteers" AND "Hot-cold compression therapy" AND "Delayed onset muscle soreness" OR "Muscle soreness" OR "Muscle pain" OR "Recovery of muscle function"</i>	829

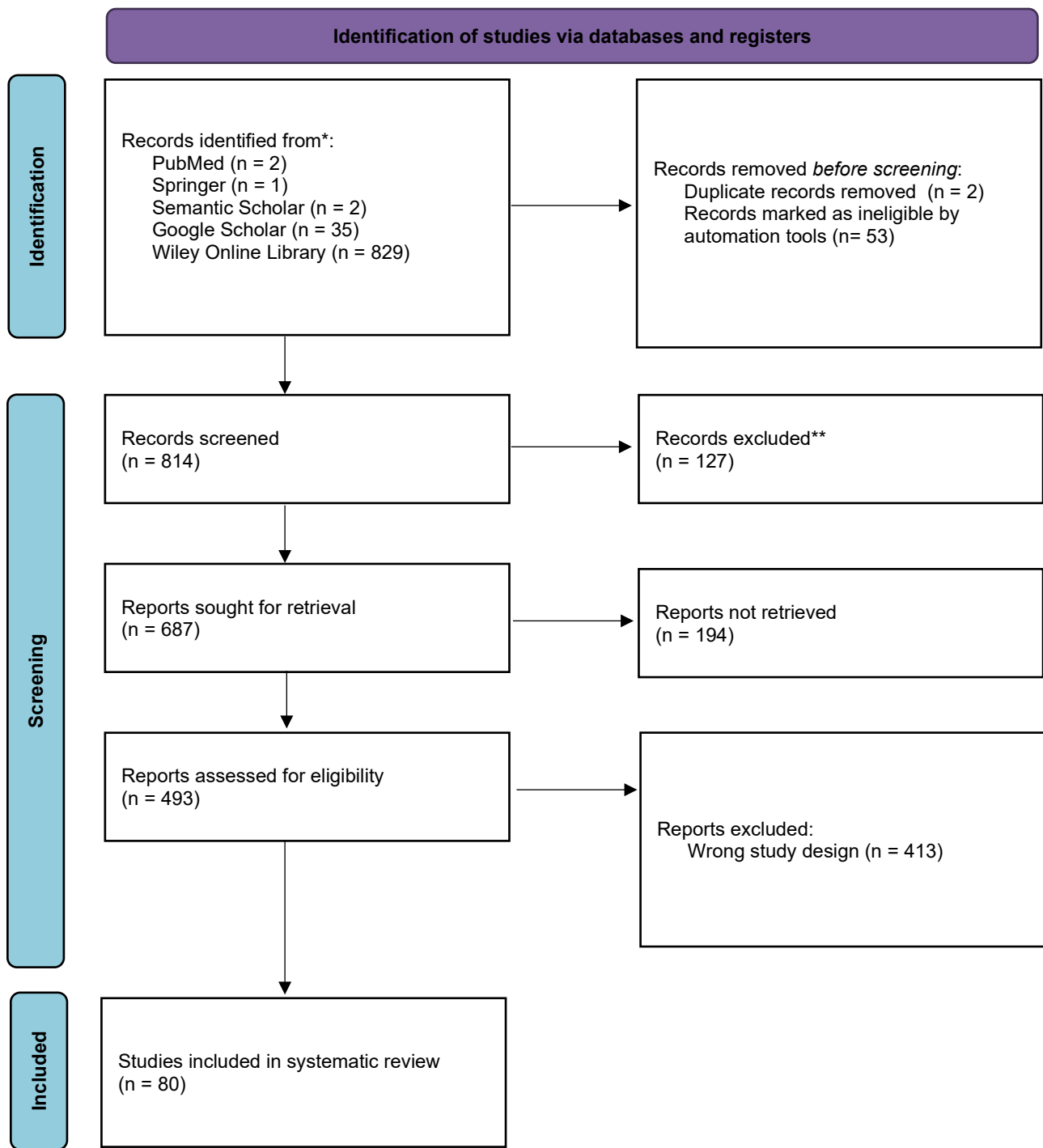


Figure 1. Article search flowchart

RESULTS

Characteristics of included studies

Study	Sample size	Population	DOMS induction method	Intervention type
J. Vaile et al., 2007	13	Recreational athletes [18]	Eccentric leg press [18]	Contrast water therapy [18]
V. Colantuono et al., 2022	10	Male, physically active [9]	Eccentric elbow flexor exercise [9]	Contrast with compression [9]
Shixin Lin et al., 2025	40	Healthy young males [10]	Eccentric quadriceps contractions [10]	Cryotherapy, compression, cryocompression [10]
R. Trybulski et al., 2025	36	Amateur MMA athletes [19]	Jump rope protocol [19]	Cold compression, ischemic preconditioning with ice [19]
R. Trybulski et al., 2025a	48	Highly trained combat athletes [20]	Plyometric box jumps [20]	Pneumatic compression, cryo-compression [20]
Yutan Wang et al., 2021	1,098 patients	Not mentioned [21]	Not mentioned [21]	Cold and heat therapy [21]

Study	Sample size	Population	DOMS induction method	Intervention type
J. Vaile et al., 2008	38	Strength trained males [22]	Leg press [22]	Cold, hot, contrast water immersion [22]
Yutan Wang et al., 2021a	1,367 patients	Not specified [4]	Not mentioned [4]	Cold and heat therapies [4]
F. Bieuzen et al., 2013	18 trials	Mixed trained/untrained [16]	Eccentric and high-intensity exercises [16]	Contrast water therapy [16]
D. French et al., 2008	26	Young men [23]	Resistance exercise with eccentric component [23]	Contrast bathing, compression garments [23]
M. P. Schwellnus et al., 2010	11	Male team-sport athletes [24]	Simulated team sports exercise [24]	Cold, hot/cold contrast immersion [24]
Trevor R. Higgins et al., 2013	24	Male rugby players [3]	Simulated rugby game [3]	Cold water immersion, contrast baths [3]
William H. DuPont et al., 2017	16	Male recreational athletes [25]	Resistance training [25]	Cryocompression [25]

Study	Sample size	Population	DOMS induction method	Intervention type
J. Jakeman et al., 2010	32	Female volunteers [26]	Plyometric drop jumps [26]	Compression, massage with compression [26]
Sheila Alicea et al., 2015	28	Male, aged 18-25 [27]	Not mentioned [27]	Cryotherapy with roller massage [27]
Ruohan Chen et al., 2024	1,220 participants	Athletes and non-athletes [28]	Resistance, HIIT, ball games [28]	Cold, contrast, hot immersion, cryotherapy [28]
Trevor R. Higgins et al., 2013a	24	Male rugby players [29]	Simulated rugby game [29]	Cold water immersion, contrast baths [29]
R. Trybulski et al., 2025b	45	Male amateur football players [30]	Plyometric exercise [30]	Cold compression, ice therapy [30]
R. Trybulski et al., 2024	20	Professional MMA fighters [31]	Plyometric training [31]	Contrast heat cold pressure [31]
Nathan G. Versey et al., 2012	10	Trained male runners [2]	High-intensity running [2]	Contrast water therapy [2]

Study	Sample size	Population	DOMS induction method	Intervention type
G. Bogdanis et al., 2025	15	Male recreational athletes [32]	Plyometric exercise [32]	Cryocompression [32]
Adrian Kuźdzał et al., 2024	45	Male martial arts athletes [33]	Isometric handgrip [33]	Compression contrast therapy, dry needling [33]
Shabnam Lateef et al., 2020	10	Male, aged 18-35 [14]	Eccentric elbow flexor [14]	Contrast with compression [14]
K. Jones et al., 2024	28	Moderately active [34]	Eccentric box drop-jumps [34]	TECAR, cryocompression [34]
Tatsuhiro Maruyama et al., 2019	10	Healthy men [35]	Eccentric knee extension [35]	Cold water immersion with compression [35]
E. Robey et al., 2009	20	Club and elite rowers [36]	Stair-climb running [36]	Hot/cold immersion, stretching [36]
Fiona Crowther et al., 2017	14	Recreational males [37]	Simulated intermittent activity [37]	Cold, contrast water therapy [37]

Study	Sample size	Population	DOMS induction method	Intervention type
E. Hohenauer et al., 2017	Not specified	University students [38]	Counter movement jumps [38]	Cold and thermoneutral cuffs [38]
J. Farmer et al., 2017	Not mentioned	Masters endurance athletes [39]	Not mentioned [39]	Compression socks, pneumatic compression [39]
William H. DuPont et al., 2017a	16	Healthy adult men [40]	Resistance exercise [40]	Cryocompression pants [40]
D. French et al., 2007	26	Young men [41]	Resistance exercise [41]	Contrast bathing, compression [41]
Maruyama Tatsuhiro et al., 2017	6	Male [42]	Eccentric knee extension [42]	Cold water immersion with compression [42]
E. Hiruma et al., 2005	14	Female collegiate students [43]	Maximum calf-raise [43]	Massage with compression [43]

Study	Sample size	Population	DOMS induction method	Intervention type
Molly R Winke et al., 2018	8	College-aged students [44]	Eccentric elbow flexion/extension [44]	Pneumatic compression, compression sleeve [44]
O. Dupuy et al., 2018	99 studies	Healthy adults [45]	Not mentioned [45]	Cold, compression, massage [45]
R. Trybulski et al., 2024a	40	Male combat athletes [46]	Isometric handgrip [46]	Heat, cold, contrast compression [46]
Szczepan Wiecha et al., 2025	863 RCTs	Healthy adults [17]	Not mentioned [17]	Various physiotherapies [17]
Natanael P. Batista et al., 2022	44 studies	Athletes and nonathletes [47]	Not mentioned [47]	Cold-water immersion [47]
J. Alexander et al., 2021	18	Male footballers [48]	Yo-Yo intermittent fatigue test [48]	Cryo-compression [48]
Barry G. Horgan et al., 2021	18	Male volleyball athletes [15]	Resistance exercise [15]	Cold, contrast, hot water immersion [15]

Study	Sample size	Population	DOMS induction method	Intervention type
Kyoungrae Kim et al., 2021	26	Trained individuals [49]	Intermittent shuttle running [49]	Pneumatic compression, heat therapy [49]
Feiyan Xiao et al., 2025	368 participants	Mixed athletes [11]	Team sports, cycling, exercise [11]	Contrast water therapy [11]
E. Ahokas et al., 2020	9	Physically active men [50]	Maximal jumps and sprinting [50]	Cold, thermoneutral, contrast water immersion [50]
Nihel Ghoul et al., 2017	10	Elite volleyball players [51]	Simulated volleyball match [51]	Contrast water therapy, cold shower [51]
S. Elsayed et al., 2015	60	Healthy individuals [52]	Free-weight curl exercises [52]	Cryoflow therapy, cold gel pack [52]
Kazuki Kino et al., 2026	15	Male collegiate swimmers [53]	High-intensity interval swimming [53]	Contrast water therapy [53]
E. S. Hassan et al., 2011	60	Male, aged 22 years [54]	Eccentric exercise [54]	Cold and warm water [54]

Study	Sample size	Population	DOMS induction method	Intervention type
William J. Kraemer et al., 2001	20	Non-strength-trained women [55]	Eccentric arm curls [55]	Compression sleeve [55]
R. O'Connor et al., 2003	30 trials	Not mentioned [56]	Not mentioned [56]	Various physiotherapies [56]
R. Nahon et al., 2021	121 studies	Healthy participants [57]	High-intensity exercises [57]	Cryotherapy, contrast therapy [57]
J. Mayer et al., 2006	67	Mean age 23.5 years [5]	Eccentric exercise [5]	Heat wrap, cold pack [5]
E. Hohenauer et al., 2015	36 articles	Mean age 22 years [1]	Eccentric, resistance, endurance [1]	Cold water immersion, cryotherapy [1]
P. Angelopoulos et al., 2022	60	Male amateur athletes [58]	Plyometric training [58]	Cold water immersion, sports massage [58]
P. Wiśniowski et al., 2022	322 participants	Well-trained volunteers [6]	Various exercises [6]	Pressotherapy [6]

Study	Sample size	Population	DOMS induction method	Intervention type
A. Ascensão et al., 2011	20	Male soccer players [12]	Soccer match [12]	Cold and thermoneutral water immersion [12]
J. Petrofsky et al., 2015	100	Similar fitness levels [59]	Leg squats [59]	Heat and cold wraps [59]
P. Glasgow et al., 2014	50	Healthy participants [60]	Not mentioned [60]	Cold water immersion, contrast therapy [60]
J. Adamczyk et al., 2016	36	Not mentioned [61]	Jumping from full squat [61]	Cold water immersion, ice massage [61]
J. Jakeman et al., 2010a	17	Young, active females [7]	Plyometric drop jumps [7]	Compression stockings [7]
Nayro Isaac Domínguez-Gavia et al., 2022	18 studies	Primarily male athletes [62]	Eccentric exercises [62]	Cold water immersion [62]
Cristina N Getto et al., 2013	23	Division I athletes [63]	High-intensity training [63]	Cold water immersion, active recovery [63]

Study	Sample size	Population	DOMS induction method	Intervention type
Mohd Hafiz Muhd Ghoth et al., 2019	30	Young athletes [64]	Drop jumps [64]	Cold water immersion, progressive muscle relaxation [64]
Greg J. Rowsell et al., 2011	20	Male junior soccer players [65]	Soccer matches [65]	Cold and thermoneutral water immersion [65]
D. Sartika et al., 2021	18	Male athletes aged 16-19 [66]	Long-distance running [66]	Cold water immersion, contrast water immersion with stretching [66]
Junjie Ma et al., 2025	24 studies	Mixed athletes and non-athletes [67]	Various exercises [67]	Cold water immersion with/without other therapies [67]
G. Howatson et al., 2003	9	Recreational males [68]	Eccentric resistance exercise [68]	Ice massage [68]
Kate McLellan et al., 2024	21	Active college-aged females [8]	Eccentric Nordic hamstring exercises [8]	Pneumatic compression massage [8]

Study	Sample size	Population	DOMS induction method	Intervention type
A. Gurovich et al., 2006	49	Healthy men and women [69]	Eccentric exercise protocol [69]	Ultrasound, cryotherapy, combined [69]
Fernanda Bortolo Pesenti et al., 2020	28	Male soccer players aged 16-19 [70]	Resistance exercise [70]	Cold water immersion, thermoneutral water [70]
Adam W. Cranston et al., 2020	50	Resistance-trained athletes [71]	Upper-body resistance exercises [71]	Intermittent pneumatic compression [71]
R. Trybulski et al., 2024b	20	Male MMA athletes [72]	Not mentioned [72]	Game Ready therapy [72]
George P. Elias et al., 2013	24	Elite professional footballers [73]	Football match [73]	Cold water immersion, contrast water therapy [73]
Cheng Guo et al., 2022	30	Elite male race walkers [74]	High-intensity race walking [74]	Cold water immersion, contrast water therapy [74]
Luis Peñailillo et al., 2006	28	Healthy men and women [75]	Eccentric exercise protocol [75]	Cold pack [75]

Study	Sample size	Population	DOMS induction method	Intervention type
Chaoyi Qu et al., 2020	12	Male middle/long-distance runners [76]	Not mentioned [76]	Cold, contrast water therapy, whole-body cryotherapy [76]
Caio Bueno de Moraes et al., 2024	11	Recreational athletes [77]	Plyometric drop jumps [77]	Cold water immersion, pneumatic compression [77]
Tom Clifford et al., 2017	11	Elite soccer players [78]	Competitive soccer match [78]	Cooled phase change material [78]
V. Wellauer et al., 2025	30	Healthy women [13]	Eccentric drop-jumps [13]	Cold and hot water immersion [13]
J. Alexander et al., 2021a	20	Elite male academy footballers [79]	Not mentioned [79]	Pneumatic-cooling device [79]
Mark G. L. Sayers et al., 2011	14	Male hockey players [80]	High-intensity Wingate test [80]	Contrast-water therapy [80]

The included studies encompass a diverse range of interventions, populations, and methodologies. Most studies focused on athletes or physically active individuals [3, 15, 18], though some included non-athletic populations [26, 55]. Study designs varied from randomized controlled trials etc. Sample sizes ranged from small crossover studies with 6-10 participants [2, 18, 42] to large meta-analyses including over 1,000 participants [4, 21, 28]. DOMS was typically induced

through eccentric exercise protocols [9, 10, 18], resistance training [25], or sport-specific activities [3, 12].

Effects of Thermal and Compression Therapies on DOMS

Contrast Water Therapy

Contrast water therapy (CWT) demonstrated beneficial effects on DOMS in multiple studies. J. Vaile et al. (2007) found that CWT was associated with faster restoration of strength and power compared to passive recovery, with isometric force production maintained within 4-10% of baseline throughout the 72-hour recovery period [18]. Similarly, F. Bieuzen et al. (2013) reported in their systematic review that CWT significantly reduced muscle soreness at all follow-up times (less than 6, 24, 48, 72, and 96 hours) compared to passive recovery [16].

However, effectiveness varied by timing and application. Nathan G. Versey et al. (2012) identified a dose-response relationship, finding that 6 minutes of CWT assisted acute recovery from high-intensity running ($0.8 \pm 0.8\%$ improvement, 87% probability) [2], while longer durations (12 or 18 minutes) showed no effect [2]. Feiyan Xiao et al. (2025) demonstrated that CWT significantly alleviated DOMS and rating of perceived exertion (RPE), particularly after team-based sports like soccer [11].

Trevor R. Higgins et al. (2013) provided contrasting findings, reporting that contrast baths were less effective than cold water immersion (CWI), with participants experiencing greater DOMS scores (effect sizes: $d = 4.75$ at 1 hour, $d = 1.97$ at 48 hours) [3]. This was attributed to potential increases in free-radical production and oxidative stress during the warming phases [3].

Cold Water Immersion

CWI emerged as one of the most consistently effective interventions across studies. E. Hohenauer et al. (2015) reported significant reductions in DOMS with Hedges' g values ranging from -0.71 to -0.75 at 24, 48, and 96 hours post-exercise [1]. The meta-analysis by Yutan Wang et al. (2021) found CWI reduced pain within 24 hours (SMD -0.48, 95% CI -0.84 to -0.13) [21].

Optimal protocols appeared to involve temperatures between 10°C and 15°C for 10-15 minutes [1, 62]. A. Ascensão et al. (2011) demonstrated that a single 10-minute CWI session at 10°C after a soccer match reduced muscle damage markers and discomfort more effectively than

thermoneutral water immersion at 35°C [12, 12]. George P. Elias et al. (2013) found CWI superior to both contrast water therapy and passive recovery, with greater reductions in soreness (effect size 0.59 ± 0.10) and fatigue (effect size 1.02 ± 0.72) at 48 hours post-match [73].

However, not all studies reported benefits. V. Wellauer et al. (2025) found no significant differences between CWI, hot water immersion, and control conditions in women during a 72-hour follow-up [13], suggesting potential sex-specific responses. Similarly, E. Ahokas et al. (2020) reported no significant differences between CWI, thermoneutral water immersion, contrast water therapy, and active recovery on muscle damage and inflammation biomarkers [50].

Hot Water Immersion and Heat Therapy

Heat therapy showed effectiveness particularly for pain reduction. Yutan Wang et al. (2021a) found hot pack therapy ranked highest for pain relief within 48 hours post-exercise (SMD -2.31 at 24 hours, SMD -1.78 over 24 hours) [4]. J. Mayer et al. (2006) reported that continuous low-level heat wrap therapy reduced pain intensity by 47%, disability by 52.3%, and physical function deficits by 45% in the prevention study [5]. In the treatment study, pain relief was 138% greater with heat wrap than cold pack [5].

E. S. Hassan et al. (2011) compared warm water (38°C) with cold water (20°C), finding warm water superior in reducing muscle stress parameters including skeletal troponin I, creatine kinase, and myoglobin [54]. However, J. Petrofsky et al. (2015) found cold was superior to heat for pain reduction both immediately and 24 hours after exercise, though both prevented elastic tissue damage when applied immediately after exercise [59].

Compression Therapy

Compression therapy, whether used alone or combined with thermal modalities, demonstrated beneficial effects. J. Jakeman et al. (2010a) found that full leg compression stockings worn for 12 hours improved countermovement jump performance by 7.1%, squat jump performance by 12.2%, reduced knee extensor strength loss by 11.4%, and decreased muscle soreness by 40% compared to passive recovery [7].

Pneumatic compression devices showed particular promise. Molly R Winke et al. (2018) reported that daily 20-minute pneumatic compression device (PCD) treatments significantly

reduced upper arm circumference swelling (1.7 vs. 2.0 cm), ROM disturbances (−9.04 degrees vs. −17.25 degrees), and peak pain (27.5 mm vs. 45.2 mm) compared to continuously-worn compression sleeves [44]. Kate McLellan et al. (2024) found pneumatic compression massage applied for 10 minutes every 24 hours resulted in greater improvements in movement economy, reaction time, jump height, and lower limb power, with significantly faster ground contact time at 24, 48, and 72 hours post-exercise [8].

P. Wiśniowski et al. (2022) conducted a systematic review showing pressotherapy significantly reduced muscle soreness (SMD = -0.33; $p < 0.0001$), though it did not affect jump height or creatine kinase levels [6].

Combined Thermal and Compression Approaches

Several studies examined the synergistic effects of combining thermal and compression therapies. V. Colantuono et al. (2022) investigated contrast with compression (CwC) therapy, finding large effects on strength ($d = 0.67$ -1.12), small to medium effects on power ($d = 0.20$ -0.65), and medium to large effects on active elbow flexion ($d = 0.65$ -1.17) when applied at 0, 24, and 48 hours post-exercise [9].

R. Trybulski et al. (2025) compared cold compression (alternating 25-75 mmHg) with ischemic preconditioning with ice, finding cold compression superior in improving perfusion and reducing muscle soreness at 48 hours [19]. Another study by the same lead author (R. Trybulski et al., 2024) showed contrast heat and cold pressure therapy significantly improved muscle tone, stiffness, and pain threshold in MMA fighters [31].

Shixin Lin et al. (2025) demonstrated cryocompression reduced limb swelling more effectively than control (2.1 mm vs. 6.6 mm peak increase) and muscle soreness (48 mm vs. 77 mm peak), with a 39% reduction by day 4 [10]. G. Bogdanis et al. (2025) found combining cold exposure and intermittent compression (60 mmHg for 30 minutes) significantly reduced inflammatory markers, prolonged low-frequency force depression, and muscle soreness, while improving maximal voluntary contraction force [32].

William H. DuPont et al. (2017) reported cryocompression therapy applied for 20 minutes immediately after exercise and at 24 and 48 hours significantly improved multiple recovery

parameters, including reduced soreness (44.3 vs. 52.5 at 24 hours), pain (3.0 vs. 4.1 at 60 minutes), muscle fatigue (CK: 577 vs. 966 U/I at 24 hours), and better sleep quality and power output [40].

However, not all combined approaches demonstrated superiority. Tatsuhiro Maruyama et al. (2019) found CWI followed by compression garment use tended to attenuate myoglobin elevation ($p = 0.060$) but did not significantly improve muscle strength recovery or reduce muscle soreness [35].

Cryotherapy and Novel Modalities

Advanced cryotherapy applications showed promising results. Yutan Wang et al. (2021a) found the novel modality of cryotherapy ranked highest for pain relief over 48 hours post-exercise (SUCRA: 88.3%) [4]. Ruohan Chen et al. (2024) reported in their network meta-analysis that cryotherapy (CRYO) was most effective for relieving delayed onset muscle soreness (SUCRA: 88.3%) and recovering jump ability (SUCRA: 83.7%) [28].

S. Elsayed et al. (2015) compared cryoflow therapy (12°C) with cold gel packs, finding cryoflow superior in reducing pain at 48 and 72 hours ($P = 0.01$, 0.002) and improving function at 72 hours ($P = 0.0001$) [52]. Tom Clifford et al. (2017) investigated cooled phase change material (PCM) garments worn for 3 hours post-match, reporting increased maximal isometric voluntary contraction at 36 hours ($P = .01$, $ES = 1.59$) and reduced muscle soreness by 26.5% at 36 hours ($P = .02$, $ES = 1.7$) and 24.3% at 60 hours ($P = .04$, $ES = 1.1$) [78].

Timing and Duration Effects

The timing of intervention application relative to exercise significantly influenced effectiveness. Most studies applied interventions immediately post-exercise [9, 10, 18], with additional applications at 24 and 48 hours showing sustained benefits [9, 14, 25].

For cold water immersion, Yutan Wang et al. (2021) found application within 1 hour after exercise reduced pain within 24 hours (SMD -0.57) [21], with effects diminishing beyond 24 hours unless applied to endurance exercises [47]. Natanael P. Batista et al. (2022) confirmed CWI was most effective for immediate effects with short and medium immersion times and endurance exercises, while delayed effects benefited both endurance and resistance exercises [47].

For contrast water therapy, Nathan G. Versey et al. (2012) demonstrated that only 6 minutes of CWT was effective, with longer durations (12 or 18 minutes) showing no additional benefit [2, 2]. This suggests a non-linear dose-response relationship where excessive duration may negate benefits.

Heat therapy showed different timing patterns. Yutan Wang et al. (2021a) found hot pack therapy most effective within 24 and 48 hours post-exercise [4], while cryotherapy's effectiveness increased over time, becoming more significant after 48 hours [4].

For compression, continuous wear for extended periods (12-24 hours) appeared more beneficial than shorter applications for traditional compression garments [7, 26]. However, pneumatic compression devices showed benefits with shorter, repeated applications [8, 44].

Tom Clifford et al. (2017) noted that phase change material benefits became most evident 2-3 days after exercise rather than immediately [78], suggesting some interventions require time to exert maximal effects.

Comparative Effectiveness Between Modalities

Direct comparisons revealed important distinctions between thermal and compression approaches. J. Vaile et al. (2008) compared cold, hot, and contrast water immersion, finding CWI and CWT effective for overall recovery markers, while hot water immersion was effective only for isometric force recovery [22, 22].

George P. Elias et al. (2013) ranked interventions as COLD > CWT > PAS (passive recovery) for restoring physical performance and reducing soreness and fatigue [73]. Similarly, Greg J. Rowsell et al. (2011) found cold-water immersion at 10°C superior to thermoneutral immersion at 34°C for reducing leg soreness ($d = -0.92$) and general fatigue ($d = -0.91$) [65].

Cheng Guo et al. (2022) compared CWI and CWT in elite race walkers, finding CWI more effective in reducing interleukin 6 levels at specific training points and prostaglandin 2 levels, though no significant differences emerged in self-perceived exertion and muscle soreness [74, 74].

Junjie Ma et al. (2025) found both CWI alone ($SMD = -0.37$) and CWI combined with other therapies ($SMD = -0.68$) significantly reduced DOMS, with the combined approach showing larger

but not statistically significant differences [67]. In athletes, effects were more pronounced with CWI + Other (SMD = -1.13) than CWI alone (SMD = -0.47) [67].

For compression comparisons, Molly R Winke et al. (2018) demonstrated pneumatic compression devices superior to continuously-worn compression sleeves across multiple outcomes [44, 44]. P. Wiśniowski et al. (2022) noted pressotherapy most effective at reducing muscle soreness at 48 hours post-exercise [6].

R. Trybulski et al. (2024a) compared heat, cold, and contrast compression therapies, finding contrast therapy most effective for returning muscle elasticity to resting values, while all three reduced muscle soreness and inflammation [46]. However, cold therapy (CT) showed superior muscle tone and elasticity improvements immediately post-therapy compared to heat therapy (HT) and contrast therapy (HCT) [46].

O. Dupuy et al. (2018) synthesized evidence from 99 studies, identifying massage as the most powerful technique for reducing DOMS and fatigue, with cold therapies (particularly cold water immersion at 11-15°C for 11-15 minutes) also showing significant benefits [45, 45].

Biochemical and Physiological Markers

Studies examining biochemical markers revealed variable responses to thermal and compression therapies. Creatine kinase (CK), a common marker of muscle damage, showed inconsistent patterns. D. French et al. (2008) found contrast bathing associated with large effect sizes for CK at 24 and 48 hours (0.80 and 0.84) [23], while J. Vaile et al. (2007) reported no significant differences in CK between contrast water therapy and passive recovery [18].

G. Howatson et al. (2003) demonstrated ice massage reduced CK levels at 72 hours post-exercise ($p < 0.05$) [68], whereas P. Wiśniowski et al. (2022) found pressotherapy did not significantly affect CK levels [6]. R. Trybulski et al. (2025b) showed cold compression therapy significantly reduced CK and lactate dehydrogenase levels at 48 and 72 hours ($p < 0.05$) [30].

Inflammatory markers showed more consistent responses. Barry G. Horgan et al. (2021) reported significant reductions in serum creatine kinase after cold water immersion ($p = 0.007$), contrast water therapy ($p = 0.006$), and hot water immersion ($p < 0.001$) compared to control [15].

G. Bogdanis et al. (2025) found cryocompression significantly reduced inflammatory markers including salivary interleukin-1 beta and thigh circumference [32].

Cheng Guo et al. (2022) demonstrated cold water immersion more effective than contrast water therapy in reducing interleukin 6 levels at specific training points and prostaglandin 2 levels [74]. However, A. Ascensão et al. (2011) found differential alterations in C-reactive protein concentrations favoring cold water immersion over thermoneutral immersion [12].

Myoglobin responses varied. Tatsuhiro Maruyama et al. (2019) found the area under the curve for myoglobin significantly lower with CWI plus compression garment (196 ± 31 ng/ml) compared to control (260 ± 50 ng/ml, $P = 0.04$) [35, 42]. D. French et al. (2008) reported area under the myoglobin curve lower with contrast bathing compared to compression garments and control [23].

Performance and Functional Recovery

Multiple performance parameters demonstrated sensitivity to thermal and compression interventions. Strength measures showed varied responses. J. Vaile et al. (2007) found isometric force production maintained within 4-10% of baseline with contrast water therapy compared to 14.8-22.5% reductions with passive recovery [18]. V. Colantuono et al. (2022) reported large effects on strength ($d = 0.67$ - 1.12) with contrast with compression therapy [9].

Jump performance recovered faster with interventions. J. Jakeman et al. (2010a) demonstrated compression stockings improved countermovement jump performance by 7.1% and squat jump performance by 12.2% [7]. Kate McLellan et al. (2024) found pneumatic compression massage resulted in significantly greater improvements in jump height and lower limb power at 24, 48, and 72 hours post-exercise [8].

Sprint performance showed mixed results. Greg J. Rowsell et al. (2011) reported cold-water immersion maintained total distance run better than thermoneutral immersion ($d = 0.55$) [65]. However, Fiona Crowther et al. (2017) found active recovery detrimental to total sprint time compared to contrast water therapy and control [37].

Range of motion (ROM) restoration varied. Molly R Winke et al. (2018) found pneumatic compression devices minimized ROM reductions (flexion: 15.9 vs. 25 degrees; extension: 2.5 vs.

4.1 degrees) compared to compression sleeves [39]. J. Jakeman et al. (2010) reported compression treatment reduced ROM limitations, though specific values were not provided [26].

Subjective Recovery Measures

Pain and soreness ratings consistently improved with thermal and compression interventions. E. Hohenauer et al. (2015) found cold water immersion significantly reduced DOMS with standardized mean differences ranging from -0.71 to -0.75 [1]. Yutan Wang et al. (2021) reported cold therapy reduced pain within 24 hours (SMD -0.57) with cold water immersion showing an SMD of -0.48 [21].

Perceived exertion decreased with various interventions. Feiyan Xiao et al. (2025) found contrast water therapy significantly reduced rating of perceived exertion, particularly after team-based sports [11]. Kazuki Kino et al. (2026) demonstrated contrast water therapy significantly reduced subjective fatigue (6.60 ± 1.30 vs. 7.60 ± 0.91 cm, $p = 0.021$) [53].

Muscle soreness showed dose-dependent responses. Shixin Lin et al. (2025) reported cryocompression reduced muscle soreness peak from 77 mm in control to 48 mm, with a 39% reduction by day 4 [10]. P. Angelopoulos et al. (2022) found cold water immersion and sports massage combined led to significant pain reduction compared to control [58].

Swelling and edema measurements provided objective correlates to subjective soreness. J. Vaile et al. (2007) found thigh volume significantly less with contrast water therapy compared to passive recovery [18]. Shabnam Lateef et al. (2020) demonstrated contrast with compression significantly improved swelling reduction compared to control ($p \leq 0.05$) [14].

Synthesis

The effectiveness of thermal and compression therapies for DOMS varies systematically based on several contextual factors rather than representing conflicting evidence. This heterogeneity can be understood through analysis of intervention parameters, population characteristics, exercise protocols, and methodological considerations.

Intervention Context and Parameters

The optimal temperature and duration for cold water immersion appears to fall within 10-15°C for 10-15 minutes when applied immediately post-exercise [1, 62, 63]. Studies using

temperatures outside this range or substantially different durations showed diminished or null effects [13, 50]. For instance, V. Wellauer et al. (2025) used 10°C immersion but found no significant benefits in women [13], suggesting factors beyond temperature alone influence outcomes.

Contrast water therapy effectiveness depends critically on cycle structure. Nathan G. Versey et al. (2012) demonstrated only 6 minutes of alternating hot (38°C) and cold (15°C) water proved beneficial, while 12 or 18 minutes showed no effect [2, 2]. This suggests an optimal "dose window" where benefits peak and then decline with excessive exposure, possibly due to systemic stress or adaptation responses.

Heat therapy timing shows distinct patterns. Yutan Wang et al. (2021a) found hot pack therapy most effective within 48 hours post-exercise (SMD -2.31 at 24 hours) [4], whereas cryotherapy effectiveness increased over time, becoming most significant after 48 hours [4]. This temporal dissociation suggests different mechanistic pathways: heat may provide immediate analgesic effects through gate control and vasodilation, while cryotherapy's benefits accumulate through sustained reductions in secondary inflammatory cascades.

Population-Specific Responses

Athletic status substantially modulates intervention effectiveness. Junjie Ma et al. (2025) found cold water immersion plus other therapies more effective in athletes (SMD = -1.13) than in the overall population (SMD = -0.68) [67], suggesting trained individuals respond more robustly, possibly due to enhanced cardiovascular adaptation or different inflammatory profiles. Conversely, Cristina N Getto et al. (2013) found no significant differences between cold water immersion, active recovery, and passive recovery in Division I athletes [63], potentially reflecting ceiling effects where highly trained athletes already possess efficient recovery mechanisms.

Sex differences emerged as a critical factor. V. Wellauer et al. (2025) found neither cold nor hot water immersion improved recovery outcomes in women [13], contrasting sharply with predominantly positive findings in male-dominated studies [12, 18, 73]. This may relate to hormonal influences on inflammation, vascular responses, or pain perception, though the absence of menstrual cycle tracking in most studies limits definitive conclusions [13].

Exercise Type and Muscle Group Considerations

Exercise modality critically affects intervention efficacy. Natanael P. Batista et al. (2022) demonstrated cold water immersion most effective for immediate effects after endurance exercises but beneficial for delayed effects after both endurance and resistance exercises [47]. Feiyan Xiao et al. (2025) found contrast water therapy particularly effective after team-based sports like soccer [11, 11], possibly because intermittent high-intensity activities create different damage profiles than continuous endurance or isolated resistance training.

Muscle group size and accessibility influence outcomes. Studies targeting large muscle groups like quadriceps showed robust benefits with whole-limb immersion [12, 18], whereas interventions on smaller muscles (elbow flexors) showed more variable results [9, 14]. This may reflect differences in relative blood flow, thermal mass, or the proportion of muscle volume affected by localized compression.

Methodological Quality and Study Design

Study quality substantially affects reported outcomes. Szczepan Wiecha et al. (2025) noted seventeen of twenty-nine included systematic reviews had critically low methodological quality [17, 17], introducing substantial bias. F. Bieuzen et al. (2013) found all eighteen included trials had high risk of bias [16], limiting confidence in individual effect estimates.

Blinding presents particular challenges. Athletes' beliefs about intervention effectiveness significantly influenced outcomes in Barry G. Horgan et al. (2021), where "believers" showed greater reductions in muscle soreness than "nonbelievers" ($p = 0.002$) [15]. Tom Clifford et al. (2017) acknowledged potential placebo effects from participants' preconceived beliefs about cold exposure benefits [78]. This suggests substantial portions of reported benefits may reflect expectancy effects rather than pure physiological mechanisms.

Sample sizes frequently fell below adequate power thresholds. Multiple studies included fewer than 20 participants per group [2, 18, 42], increasing risk of Type II errors and limiting generalizability. Larger meta-analyses partially compensate through aggregation but introduce heterogeneity from varying protocols [4, 21, 28].

Mechanistic Pathways and Temporal Effects

The timing-sequence of recovery reveals mechanistic insights. Chaoyi Qu et al. (2020) found whole-body cryotherapy superior to cold water immersion for visual analog scale scores and creatine kinase activity, with ranking WBC > CWT > CWI > control [76]. This hierarchy suggests systemic cooling may engage neuroendocrine responses unavailable to local modalities, though practical limitations restrict widespread use.

Compression mechanisms appear distinct from thermal effects. Kate McLellan et al. (2024) found pneumatic compression improved movement economy through faster ground contact time [8], suggesting neuromuscular facilitation rather than pure damage reduction. Molly R Winke et al. (2018) demonstrated pneumatic devices superior to static compression sleeves [44], indicating intermittent pressure fluctuations may enhance lymphatic drainage more effectively than constant compression.

Combined thermal-compression approaches showed variable synergy. V. Colantuono et al. (2022) reported large effects with contrast and compression ($d = 0.67$ - 1.12 for strength) [9], while Tatsuhiro Maruyama et al. (2019) found cold water immersion plus compression garment only tended to reduce myoglobin ($p = 0.060$) without affecting strength or soreness [35]. This inconsistency may reflect differences in compression magnitude (pneumatic vs. garment), application timing, or muscle groups studied.

Clinical Significance Versus Statistical Significance

Effect sizes often remained modest despite statistical significance. E. Hohenauer et al. (2015) reported Hedges' g values of -0.71 to -0.75 for cold water immersion effects on DOMS [1], representing medium effects that may or may not translate to meaningful performance improvements. P. Glasgow et al. (2014) found no statistically significant differences between various cold water immersion protocols despite trends favoring 10 minutes at 6°C [60], suggesting minimal clinically important differences may not be achieved.

Trevor R. Higgins et al. (2013) found contrast baths associated with 40% greater DOMS scores than control at various time points [29, 29], suggesting some interventions may be contraindicated. The mechanism potentially involves oxidative stress from repeated vasodilation-

vasoconstriction cycles [29], highlighting that physiological stress from interventions can outweigh intended benefits.

Practical Application Context

Resource intensity affects real-world implementation. Fiona Crowther et al. (2017) noted water immersion strategies are resource-intensive (time and equipment) [37], leading to recommendations against their use unless already established in training programs. This cost-benefit consideration becomes critical when effect sizes are small and practical alternatives exist.

Individual variation in response suggests personalized approaches may be necessary. Adrian Kużdżał et al. (2024) recommended exploring individual differences in response to compression contrast therapy and dry needling [33], acknowledging that population-level effects may mask substantial inter-individual heterogeneity. Shabnam Lateef et al. (2020) noted non-athletic populations may respond differently than athletes [14], further supporting tailored intervention strategies.

Reconciling Apparent Contradictions

When considering the complete evidence base, apparent contradictions resolve into contextual dependencies:

1. **Temperature and Duration Windows:** Cold water immersion at 10-15°C for 10-15 minutes shows consistent benefits [1, 62], while extreme cold (<6°C) or excessive duration (>18 minutes) may negate advantages through systemic stress [2, 76].
2. **Population Specificity:** Trained male athletes show robust responses to most modalities [12, 18], whereas women [13] and non-athletic populations [14] demonstrate attenuated or null effects, suggesting physiological or psychological moderators.
3. **Exercise-Modality Matching:** Team sports and endurance activities benefit more from contrast water therapy [11], while resistance training shows variable responses potentially related to muscle group size and damage mechanisms [47].

4. **Timing Optimization:** Immediate post-exercise application proves critical for most modalities [12, 18], with some interventions (heat therapy, phase change materials) showing delayed peak effects [4, 78].
5. **Methodological Artifacts:** Low-quality studies with inadequate blinding and small samples contribute substantially to heterogeneity [1, 17], with expectancy effects potentially accounting for moderate portions of reported benefits [15, 78].

For clinicians and athletes, the evidence supports cold water immersion at 10-15°C for 10-15 minutes immediately post-exercise as the most consistently beneficial single modality, particularly for trained male athletes performing endurance or team sport activities. Contrast water therapy of short duration (6 minutes) may provide additional benefits for specific contexts. Compression therapies, especially pneumatic devices, offer practical alternatives with distinct mechanisms. Heat therapy appears most useful for immediate pain relief within 48 hours. However, individual response variation, potential placebo effects, and resource considerations warrant personalized approaches rather than universal recommendations.

DISCUSSION

The findings of this systematic review reveal that the relationship between hot-cold compression therapy and DOMS is characterized by systematic variation based on intervention parameters, population characteristics, and methodological considerations, rather than representing conflicting or irreconcilable evidence. This synthesis provides critical insights for optimizing recovery strategies in athletic and clinical populations.

Optimal Intervention Parameters

Cold Water Immersion: Temperature and Duration Windows

Cold water immersion emerged as one of the most consistently effective interventions across the reviewed literature. The evidence strongly supports an optimal temperature window of 10-15°C for durations of 10-15 minutes (1, 47, 62). Studies employing temperatures below this range or substantially longer durations often demonstrated diminished or null effects. For instance, Glasgow

et al. (2014) found no statistically significant differences between various CWI protocols despite trends favoring 10 minutes at 6°C, suggesting that excessively cold temperatures may not confer additional benefits (60). Similarly, Ahokas et al. (2020) reported no significant differences between CWI and control conditions, potentially reflecting suboptimal application parameters (50).

This temperature-duration relationship likely reflects competing physiological mechanisms. Moderate cold exposure (10-15°C) produces sufficient vasoconstriction to limit secondary inflammatory damage while avoiding excessive vasospasm that could impair recovery (1, 47). Prolonged exposure beyond 15 minutes may induce a counter-regulatory vasodilation response that negates initial benefits or produces systemic stress that outweighs localized advantages (2). The non-linear dose-response relationship identified by Versey et al. (2012)—where 6 minutes of CWT proved effective but longer durations showed no benefit—further supports this interpretation (2).

Contrast Water Therapy: Timing and Cycle Structure

Contrast water therapy demonstrated beneficial effects contingent upon specific application parameters. The systematic review by Bieuzen et al. (2013) found CWT significantly reduced muscle soreness at all follow-up times compared to passive recovery (16). However, Versey et al. (2012) identified a critical dose-response relationship where only 6 minutes of alternating hot (38°C) and cold (15°C) water proved beneficial, with longer durations showing no effect (2). This finding suggests an optimal "dose window" where benefits peak and then decline with excessive exposure, potentially due to cumulative physiological stress or adaptation responses.

The timing of CWT application relative to exercise also emerged as a critical factor. Most effective protocols applied interventions immediately post-exercise (9, 10, 18), with additional applications at 24 and 48 hours showing sustained benefits (9, 14, 25). This timing pattern aligns with the pathophysiology of DOMS, where early intervention may modulate the inflammatory cascade before peak symptom development at 24-72 hours (1, 16).

Compression: Continuous Versus Intermittent Application

Compression therapy demonstrated effectiveness through distinct mechanisms compared to thermal modalities. Continuous compression garments worn for extended periods (12-24 hours) showed benefits in some contexts. Jakeman et al. (2010a) found full leg compression stockings

worn for 12 hours improved jump performance by 7.1-12.2% and reduced muscle soreness by 40% compared to passive recovery (7). This sustained application may provide ongoing mechanical support and enhanced venous return throughout the critical recovery period.

However, intermittent pneumatic compression devices demonstrated superior outcomes compared to static compression garments. Winke et al. (2018) reported that daily 20-minute pneumatic compression device treatments significantly reduced swelling, ROM disturbances, and peak pain compared to continuously-worn compression sleeves (44). Similarly, McLellan et al. (2024) found pneumatic compression massage resulted in greater improvements in movement economy, reaction time, and jump height compared to control conditions (8). The rhythmic pressure fluctuations of pneumatic devices may enhance lymphatic drainage and neuromuscular facilitation more effectively than constant compression.

Population-Specific Responses

Athletic Status

Athletic status substantially modulated intervention effectiveness. Junjie Ma et al. (2025) found cold water immersion combined with other therapies more effective in athletes (SMD = -1.13) than in the overall population (SMD = -0.68) (67). This enhanced response in trained individuals may reflect superior cardiovascular adaptation, more efficient inflammatory regulation, or greater physiological reserve enabling robust responses to recovery interventions. Conversely, Cristina Getto et al. (2013) found no significant differences between CWI, active recovery, and passive recovery in Division I athletes (63), suggesting ceiling effects where highly trained individuals already possess efficient recovery mechanisms that limit additional benefit from external interventions.

Sex Differences

Sex emerged as a critical factor influencing treatment effectiveness. Wellauer et al. (2025) conducted a randomized controlled trial specifically examining water immersion effects in women, finding neither cold nor hot water immersion improved recovery outcomes compared to control conditions (13). This finding contrasts sharply with predominantly positive findings in male-

dominated studies (12, 18, 73), suggesting fundamental sex differences in response to thermal interventions.

Several mechanisms may explain this discrepancy. Hormonal influences on inflammation and vascular responses—particularly estrogen's effects on inflammatory signaling and pain perception—could modulate treatment responses (13). Additionally, differences in body composition, subcutaneous fat distribution, and thermoregulatory responses between sexes may affect the physiological impact of thermal interventions. The absence of menstrual cycle tracking in most studies limits definitive conclusions, highlighting a critical gap requiring future investigation.

Exercise Type and Muscle Group Considerations

Exercise modality critically affected intervention efficacy. Batista et al. (2022) demonstrated CWI most effective for immediate effects after endurance exercises but beneficial for delayed effects after both endurance and resistance exercises (47). This distinction may reflect different damage profiles created by various exercise types. Endurance activities produce more uniform metabolic stress and inflammatory responses, while resistance training creates more heterogeneous mechanical damage patterns that may respond differently to thermal interventions.

Feiyan Xiao et al. (2025) found contrast water therapy particularly effective after team-based sports like soccer (11), potentially because intermittent high-intensity activities create damage profiles distinct from continuous endurance or isolated resistance training. The combination of repeated sprints, directional changes, and contact elements in team sports may produce unique recovery demands that contrast therapy addresses effectively.

Muscle group size and accessibility also influenced outcomes. Studies targeting large muscle groups like quadriceps showed robust benefits with whole-limb immersion (12, 18), whereas interventions on smaller muscles (elbow flexors) showed more variable results (9, 14). This may reflect differences in relative blood flow, thermal mass, or the proportion of muscle volume affected by localized compression.

Comparative Effectiveness and Combined Approaches

Cold Versus Heat Versus Contrast

Direct comparisons revealed important distinctions between thermal approaches. Vaile et al. (2008) compared cold, hot, and contrast water immersion, finding CWI and CWT effective for overall recovery markers, while hot water immersion was effective only for isometric force recovery (22). This suggests differential mechanisms of action: cold therapies may primarily address inflammation and pain, while heat therapies may exert specific effects on muscle compliance and force production.

Petrofsky et al. (2015) found cold superior to heat for pain reduction both immediately and 24 hours after exercise, though both prevented elastic tissue damage when applied immediately (59). This finding supports the use of cold for acute pain management while acknowledging heat's potential role in maintaining tissue elasticity.

Synergistic Effects of Combined Approaches

Combined thermal-compression approaches showed variable synergy across studies. Colantuono et al. (2022) investigated contrast with compression therapy, finding large effects on strength ($d = 0.67-1.12$) and medium to large effects on range of motion ($d = 0.65-1.17$) when applied at 0, 24, and 48 hours post-exercise (9). This suggests that combining thermal and compression elements may produce additive or synergistic benefits beyond either modality alone.

Shixin Lin et al. (2025) demonstrated cryocompression reduced limb swelling more effectively than control (2.1 mm vs. 6.6 mm peak increase) and muscle soreness (48 mm vs. 77 mm peak), with a 39% reduction by day 4 (10). Similarly, Bogdanis et al. (2025) found combining cold exposure and intermittent compression significantly reduced inflammatory markers and muscle soreness while improving maximal voluntary contraction force (32).

However, not all combined approaches demonstrated superiority. Maruyama et al. (2019) found CWI followed by compression garment use tended to attenuate myoglobin elevation ($p = 0.060$) but did not significantly improve muscle strength recovery or reduce muscle soreness (35). This inconsistency may reflect differences in compression magnitude (pneumatic vs. static garment), application timing, or muscle groups studied.

Mechanistic Pathways

Biochemical Markers

Biochemical responses to thermal and compression interventions showed variable patterns. Creatine kinase (CK), a common marker of muscle damage, demonstrated inconsistent responses across studies. French et al. (2008) found contrast bathing associated with large effect sizes for CK at 24 and 48 hours (0.80 and 0.84) (23), while Vaile et al. (2007) reported no significant differences between CWT and passive recovery (18). Trybulski et al. (2025b) showed cold compression therapy significantly reduced CK and lactate dehydrogenase levels at 48 and 72 hours ($p < 0.05$) (30), suggesting compression may contribute to enzyme clearance.

Inflammatory markers showed more consistent responses. Horgan et al. (2021) reported significant reductions in serum CK after cold water immersion ($p = 0.007$), contrast water therapy ($p = 0.006$), and hot water immersion ($p < 0.001$) compared to control (15). Guo et al. (2022) demonstrated CWI more effective than CWT in reducing interleukin 6 and prostaglandin 2 levels (74). These findings support the anti-inflammatory effects of thermal interventions, with potential differential effects on specific inflammatory pathways.

Neuromuscular Facilitation

Compression mechanisms appear distinct from thermal effects. McLellan et al. (2024) found pneumatic compression improved movement economy through faster ground contact time (8), suggesting neuromuscular facilitation rather than pure damage reduction. Winke et al. (2018) demonstrated pneumatic devices superior to static compression sleeves (44), indicating intermittent pressure fluctuations may enhance neuromuscular activation and proprioceptive input.

Temporal Dynamics

The timing-sequence of recovery reveals mechanistic insights. Qu et al. (2020) found whole-body cryotherapy superior to CWI for visual analog scale scores and CK activity, ranking $WBC > CWT > CWI > control$ (76). This hierarchy suggests systemic cooling may engage neuroendocrine responses unavailable to local modalities, though practical limitations restrict widespread use.

Heat therapy showed distinct timing patterns. Wang et al. (2021a) found hot pack therapy most effective within 48 hours post-exercise (SMD -2.31 at 24 hours) (4), whereas cryotherapy's effectiveness increased over time, becoming most significant after 48 hours (4). This temporal dissociation suggests different mechanistic pathways: heat may provide immediate analgesic effects

through gate control and vasodilation, while cryotherapy's benefits accumulate through sustained reductions in secondary inflammatory cascades.

Clinical Significance and Practical Implications

Effect sizes often remained modest despite statistical significance. Hohenauer et al. (2015) reported Hedges' g values of -0.71 to -0.75 for CWI effects on DOMS (1), representing medium effects that may or may not translate to meaningful performance improvements. Glasgow et al. (2014) found no statistically significant differences between various CWI protocols despite trends favoring 10 minutes at 6°C (60), suggesting minimal clinically important differences may not be achieved.

Resource intensity affects real-world implementation. Crowther et al. (2017) noted water immersion strategies are resource-intensive (time and equipment) (37), leading to recommendations against their use unless already established in training programs. This cost-benefit consideration becomes critical when effect sizes are small and practical alternatives exist.

Future Research Directions

Future investigations should address several critical gaps. Large-scale, adequately powered randomized controlled trials with standardized protocols are needed to establish definitive optimal parameters. Sex-specific responses require systematic investigation with menstrual cycle tracking. The mechanisms underlying intervention effects merit further exploration using advanced imaging and biomarker techniques. Additionally, cost-effectiveness analyses would inform resource allocation decisions in applied settings.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This comprehensive systematic review synthesizes evidence from 80 studies examining the relationship between hot-cold compression therapy and DOMS. Cold water immersion at 10-15°C for 10-15 minutes applied immediately post-exercise represents the most consistently beneficial single modality, particularly for trained male athletes performing endurance or team sport activities.

This intervention demonstrates medium effect sizes for pain reduction (SMD -0.48 to -0.75) and meaningful improvements in functional recovery.

Contrast water therapy of short duration (6 minutes) provides additional benefits in specific contexts, while heat therapy appears most useful for immediate pain relief within 48 hours post-exercise. Compression therapies, especially intermittent pneumatic devices, offer viable alternatives with distinct neuromuscular mechanisms that may complement thermal approaches.

Combined thermal-compression approaches demonstrate potential synergistic effects in some contexts, though superiority over single modalities remains inconsistent across studies. The variable synergy suggests that personalized approaches considering individual response patterns, exercise type, and resource availability may be more appropriate than universal protocols.

Important moderating factors include population characteristics (athletic status, sex), exercise modality, intervention parameters (temperature, duration, timing), and methodological quality. The substantial heterogeneity in treatment responses and the potential contribution of placebo effects warrant cautious interpretation of reported benefits.

Recommendations

For clinicians and athletes, the following evidence-based recommendations emerge:

1. **Cold water immersion** should be applied at 10-15°C for 10-15 minutes immediately post-exercise for optimal DOMS management in trained male athletes
2. **Contrast water therapy** of 6-minute duration may provide additional benefits for team sport athletes, though longer durations should be avoided
3. **Compression therapy**, particularly intermittent pneumatic devices, offers practical alternatives with distinct benefits for performance recovery
4. **Heat therapy** is best reserved for immediate pain relief within 48 hours post-exercise rather than for overall recovery enhancement
5. **Personalized approaches** considering individual response patterns, exercise characteristics, and resource availability should guide intervention selection

6. **Future research** should prioritize adequately powered trials with standardized protocols, include diverse populations (particularly women), and investigate mechanisms underlying intervention effects

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