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Research Question: *Examining the Role of Cryotherapy in Accelerating Recovery Post-Exercise.*

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Abstract:

This study examines the role of cryotherapy in accelerating recovery following exercise, with emphasis on cellular, biochemical and performance-related outcomes. By drawing on historical, physiological and applied perspectives, the paper explores how cryotherapy has evolved from ancient therapeutic practices to contemporary athletic recovery modalities. The research paper gives particular attention to its influence on biochemical markers, such as interleukin-6 (IL-6), creatine kinase (CK) and reactive oxygen species (ROS), which serve as indicators of inflammation, muscle damage and oxidative stress. The findings highlight the advantages and limitations of cryotherapy. This includes its capacity to reduce muscle soreness and inflammation, while raising concerns regarding potential interference with

adaptive training responses. The future implications include optimising cryotherapy protocols for athletes of different age groups and genders, and identifying contexts where its benefits outweigh its drawbacks.

Keywords:
Post-Exercise Recovery; Cryotherapy; Sports Injury; Physical Therapy; Inflammation Reduction; Muscle Soreness; Localised Cryotherapy; Cold-induced Biochemical Kinetics; Inflammatory Cytokines (IL-6, CK); Athletic Performance Recovery; Topical Cold Therapy; Creatine Kinase; Muscle Damage; Gender-Specific Recovery; Age-Related Recovery

Introduction

The Importance of Post-Exercise Recovery

Post-exercise recovery is critical for optimising athletic performance, preventing injuries and ensuring long-term musculoskeletal health. Adequate recovery periods allow the body to repair muscle tissue, replenish energy stores, reduce inflammation and adapt to the stress of training (Naderi et al., 2025). Thus, without sufficient recovery, athletes are at a higher risk of overuse injuries, decreased performance and chronic fatigue (Kenttä & Hassmén, 1998). One recovery method is cryotherapy. This review analyses the effects of cryotherapy and its differences in female and male athletes of various age groups.

What Cryotherapy Means

Cryotherapy is derived from the Greek word ‘cryos’, which means cold (Samant et al., n.d.). This method aims to reduce the temperature of a tissue for therapeutic and healing purposes (F. Nadler, n.d.).

The History of Cryotherapy and How Cryotherapy is Used Currently

According to research, the physiological effects of cryotherapy were first discovered in Ancient Greece. Its effects were first recorded by Hippocrates, a well-known physician. He believed that cryotherapy was useful in preventing energy and strength depletion. Hippocrates used cryotherapy to treat oedema. He found that using cold application reduced swelling. Cryotherapy is still used as a method to reduce and treat oedema (Allan et al., 2022). Oedema is an accumulation of fluid in the interstitial space that occurs as the capillary filtration exceeds the limits of lymphatic drainage. It is characterised by swelling of tissue, which can be seen as visibly larger than usual (Gonem, 2017).

Since Hippocrates’ discovery, the use of cryotherapy has been explored in various contexts, including spasticity and hypertonus of muscles, soft tissue injuries, arthritides and pain (Fialka, 1994). Spasticity is a pathological condition which represents hyperactivity of the stretch reflex in response to movement (Kelly, n.d.). Hypertonus or hypertonia refers to an abnormally high level of muscle tension. It can be diagnosed by using a combination of physical examinations, neurological assessments, and in some cases, imaging or genetic tests (Marashly, 2023).

Soft tissue is a general term which refers to various groups of cells in the human body. Soft tissues, especially arterial smooth muscles, ligaments and tendons in joints of the human body, can be injured or damaged by excessive force applied during exercise (Li, 2016). Arthritides is a general term which encompasses various inflammatory and non-inflammatory joint conditions that are characterised by pain, stiffness and swelling in one or more joints (Caporali et al., 2009).

The methods of application of cryotherapy are diverse. This includes ice packs (that means local application), cold-water immersion (CWI) and whole-body cryotherapy (WBC) (non-local application) (Garcia et al., 2021). According to research, CWI remains the most extensively studied technique. It is often applied for 10 to 15 minutes at 10 to 15 °C (Machado et al., 2016). Evidence shows that CWI can reduce delayed-onset muscle soreness (DOMS) and perceived fatigue. In saying that, the performance recovery outcomes may vary (Wilson et al., 2019).

On another level, WBC is where athletes are briefly exposed to extremely cold air (between −110°C to −140 °C). This method has gained popularity in elite sports. WBC can reduce systemic inflammation and create faster restoration of muscle function (C. Rose et al., 2017). It is important to note that the systematic reviews highlight that protocols are not standardised and accessibility to whole-body cryotherapy remains limited in different parts of the world (Ihsan et al., 2021).

Additionally, other techniques can include ethyl chloride and other cooling sprays, gel packs, refrigerant gases and inflatable splints (Ernst & Fialka, 1994; Swenson et al., 1996). Ethyl chloride spray is a common cooling modality, which has been widely used in acute sports injuries and joint injection procedures (Rui et al., 2017). Ethyl chloride has a boiling point of -12°C; therefore, it evaporates extremely fast and leaves the skin cool. Spraying for 5 to 7 seconds lowers surface temperature around 5 - 10 °C, and short bursts under 3 seconds reach approximately 15 °C (Im et al., 2012). Studies have indicated ethyl chloride is not a standalone treatment for muscular injuries. However, remains part of the first-aid kit used for first response for treating acute sport-related injuries and joint-related injuries (James & Drez, 1988).

Background on Cryotherapy in Connection to Athletic Recovery

Cryotherapy has long been used in sports medicine to enhance recovery following intense physical activity (Meeusen & Lievens, 1986). The fundamental rationale behind using cryotherapy is the reduction of tissue temperature. This leads to decreased blood flow, reduced metabolism and attenuated inflammatory responses. Thus, potentially accelerating muscular recovery and performance restoration (Hohenauer et al., 2015; White & Wells, 2013)

Athletes frequently employ various cryotherapy methods. This includes ice packs, CWI, and vapocoolant sprays. Each method varies in cooling intensity and tissue penetration depth (Machado et al., 2016; Wilson et al., 2019). While whole-body cryotherapy has gained popularity for systemic recovery, localised cryotherapy remains a more accessible and targeted approach. It is often preferred for its simplicity and precision in targeting specific muscle groups (Ihsan et al., 2016; C. Rose et al., 2017). Recent meta-analyses have demonstrated promising outcomes with localised cryotherapy, particularly in decreasing inflammation markers and subjective measures of muscle soreness post-exercise (Higgins et al., 2017).

Objectives and Hypothesis

Despite widespread adoption, research has indicated that debates persist regarding optimal protocol parameters, such as duration and modality, and the physiological mechanisms underlying the observed benefits of cryotherapy (Allan et al., 2022). This review aims to address such gaps by systematically analysing biochemical markers, such as IL-6, CK and ROS. In addition, evaluating evidence which supports the efficacy of localised cryotherapy in athletic recovery contexts, such as being female or male, and of different age groups.

Literature Review:

Recognising Potential Cellular and Molecular Mechanisms of Cryotherapy

Cryotherapy can influence body recovery and adaptation. It focuses on vascular responses, sensory transduction, inflammatory modulation, oxidative stress, mitochondrial function, muscle repair and apoptosis. Vascular responses refer to when blood vessels dynamically adjust their diameter in response to various stimuli (Navedo et al., 2025). Sensory transduction is defined as the process by which energy from the external world is transformed into energy within the internal world (Yoshioka & Sakakibara, 2013). Oxidative stress is a concept which is caused by an imbalance between the production and accumulation of oxygen reactive species (ROS) in cells and tissues, and the ability of a biological system to detoxify these reactive products (Pizzino et al., 2017). Apoptosis is a series of molecular steps in a cell that lead to its death (National Cancer Institute, n.d.).

At the molecular level, cryotherapy can blunt exercise-induced elevations in pro-inflammatory cytokines, such as interleukin-6 (IL-6), tumour necrosis factor-alpha (TNF-α) and interleukin-1 beta (IL-1β) (Banfi et al., 2010). While IL-6 plays regenerative and metabolic roles, its acute suppression by cold may reduce the DOMS and secondary injury (Lombardi et al., 2017). TNF-α is an inflammatory cytokine that is produced by macrophages/monocytes during acute inflammation. It is responsible for a diverse range of signalling events within cells, leading to necrosis or apoptosis (Idriss & Naismith, 2000). IL-1β is a pro-inflammatory cytokine which is essential for cellular defence and repair for nearly all tissues (Shaikh, 2011).

Exercise increases the generation of reactive oxygen and nitrogen species (ROS/RNS), contributing to oxidative damage in skeletal muscle (Peake et al., 2017). Cryotherapy attenuates post-exercise oxidative stress, preserving redox balance and limiting cellular damage (Ferreira-Junior et al., 2015). However, because ROS also function as signalling molecules for adaptation, repeated suppression could impede training-induced improvements (Buresh & Berg, 2011).

Importance of Biochemical Markers in Post-Exercise Recovery: IL-6, CK and ROS

Cryotherapy exerts its effects primarily by lowering tissue temperature, which induces vasoconstriction, reduces local blood flow and slows cellular metabolism (White & Wells, 2013). These mechanisms attenuate the acute inflammatory response and reduce secondary muscle damage, following intense activity (Hohenauer et al., 2015). Research highlights that cryotherapy may also modulate sensory input, reducing pain perception through the gate control theory of pain (Swenson et al., 1996).

The Gate Control Theory of Pain, first proposed by Melzack and Wall in 1965, suggests that pain signals must pass through a 'gate' mechanism in the spinal cord before reaching the brain, and that this gate can be modulated by both sensory input and psychological factors. Cryotherapy interacts directly with this mechanism by stimulating cold-sensitive receptors in the skin. The strong sensory input from cold application competes with and partially blocks the transmission of pain signals from injured or fatigued tissues, effectively 'closing the gate' and reducing the perception of pain. In addition, cryotherapy decreases nerve conduction velocity and dampens local inflammatory responses, producing a combined effect that alleviates soreness and accelerates the perception of recovery. This dual action highlights how cryotherapy not only influences physiological healing but also fits within the broader neurological framework of pain modulation (Mendell, 2013).

Biochemical markers, such as interleukin-6 (IL-6), creatine kinase (CK) and reactive oxygen species (ROS), serve as critical indicators of physiological stress and muscle recovery following exercise (Dupuy et al., 2018; Peake et al., 2017). Interleukin-6 (IL-6) is a multifunctional cytokine released during and after exercise, where it plays both pro-inflammatory and anti-inflammatory roles. It is often elevated after strenuous exercise or physical activity. It reflects inflammatory stress, muscle tissue inflammation and muscle fibre microtrauma (Steensberg et al., 2000). IL-6's timely regulation is essential for efficient recovery and adaptation (Fischer, 2006; Pedersen & Febbraio, 2008).

Biologically, it acts as a pro-inflammatory signal, initiating immune activity to support tissue repair (Tanaka et al., 2014). Second, as a myokine released by contracting skeletal muscle, IL-6 enhances glucose uptake and lipid metabolism by activating AMPK and promoting fat oxidation and stimulates anti-inflammatory mediators, such as IL-1 receptor antagonist (IL-1ra) and IL-10 (Severinsen & Pedersen, 2020; Petersen & Pedersen, 2005). CK is an enzyme that is released from damaged muscle fibres. It provides a reliable marker for muscle damage severity and helps combat post-exercise muscular strain. Cryotherapy has been associated with lower post-exercise CK levels, suggesting a protective effect on muscle integrity (Brancaccio et al., 2010; Clarkson & Hubal, 2002).

On another level, ROS are chemically reactive molecules which are generated by mitochondrial metabolism during exercise (Juan et al., 2021). While reactive oxygen species are essential at moderate levels for physiological adaptations, excessive amounts can lead to oxidative damage, delayed recovery and impaired muscle function (Margaritelis et al., 2018; Powers et al., 2016). Therefore, assessing these biochemical markers can provide valuable insights in terms of the effectiveness of using cryotherapy as a recovery strategy and guide practical recommendations for athletes and coaches.

Effects of Cryotherapy on IL-6 Levels

Interleukin-6 (IL-6) is a multifunctional cytokine released during and after exercise, where it plays both pro-inflammatory and anti-inflammatory roles. Following strenuous physical activity, skeletal muscles act as a major source of IL-6, with concentrations rising sharply as a response to muscle fibre stress and microtrauma (Steensberg et al., 2000). Biologically, IL-6 serves two primary purposes. First, it functions as an inflammatory signal, activating immune cells to initiate tissue repair. Second, it acts as a myokine, supporting glucose uptake and lipid metabolism to meet the increased energy demands of exercising muscle, while also stimulating anti-inflammatory cytokines such as interleukin-10 (Pedersen & Febbraio, 2008).

The application of cryotherapy has been shown to blunt this post-exercise rise in IL-6 (Banfi et al., 2010). This reduction occurs primarily due to vasoconstriction and a lowering of local metabolic activity, which together limit the recruitment of immune cells and the release of cytokines from damaged tissue (Guillot et al., 2019). Vasoconstriction is the physiological process in which blood vessels narrow due to contraction of the smooth muscle in their walls, leading to reduced blood flow and heat loss in the affected tissue (Kellogg, 2006). In the context of cryotherapy, vasoconstriction helps limit inflammation, swelling, and metabolic demand in injured or stressed muscles (Peake et al., 2015; Pournot et al., 2011b).

By moderating IL-6 levels, cryotherapy helps reduce inflammation and may lessen DOMS, leading to faster subjective recovery (Lewis et al., 2012). However, the biological implications of suppressing IL-6 are complex. While reduced levels can prevent excessive inflammation and secondary muscle damage, IL-6 is also involved in long-term training adaptations (Muñoz-Cánoves et al., 2013). Pathways such as JAK/STAT3 and AMPK, IL-6 contribute to mitochondrial biogenesis, glucose regulation, and muscle regeneration (Chen et al., 2023; Peake et al., 2015). Mitochondrial biogenesis is the process of generating new mitochondria within skeletal muscle cells, which enhances energy production capacity (Chen et al., 2023). After intense exercise, this adaptation improves endurance and accelerates recovery. Cryotherapy, by modulating IL-6 levels, may therefore influence how efficiently muscles restore their energy-producing capacity post-exercise.

Glucose regulation refers to the uptake and utilisation of glucose by muscle cells to restore glycogen stores and fuel post-exercise recovery (A. J. Rose & Richter, 2005). IL-6 functions as a myokine during exercise, enhancing glucose uptake and lipid metabolism to meet energy demands (Pedersen & Febbraio, 2008). Moderate use supports reduced fatigue and faster readiness for performance, though excessive suppression of IL-6 might impair these metabolic benefits. While lowering excessive IL-6 helps reduce inflammation, chronic suppression could also dampen these beneficial adaptations.

Muscle regeneration is the repair and rebuilding of damaged muscle fibres after exercise-induced stress (Tidball, 2011). IL-6 contributes by recruiting immune cells and activating satellite cells that facilitate muscle repair and growth (Serrano et al., 2008).

Therefore, repeated suppression of IL-6 through regular post-exercise cryotherapy may diminish the signalling required for optimal physiological adaptation, potentially limiting improvements in endurance and hypertrophy.

Effects of Cryotherapy on CK Levels

Creatine kinase (CK) is an intracellular enzyme involved in energy metabolism, specifically in the rapid regeneration of adenosine triphosphate (ATP) within muscle cells (Wallimann et al., 2011). During intense or prolonged exercise, disruption of muscle fibres leads to leakage of CK into the bloodstream, making it one of the most widely used biomarkers of exercise-induced muscle damage (Brancaccio et al., 2010; Clarkson & Hubal, 2002). Elevated CK levels are strongly correlated with the severity of muscle strain and are often accompanied by symptoms of DOMS (Gleeson et al., 1995).

Cryotherapy has been reported to attenuate post-exercise elevations in CK, suggesting a protective effect on muscle fibre integrity (Higgins et al., 2017). The proposed mechanisms include a reduction in muscle membrane permeability due to vasoconstriction, decreased infiltration of inflammatory cells, and mitigation of secondary tissue damage (Bleakley et al., 2012). By lowering the leakage of CK into circulation, cryotherapy may accelerate the repair process and reduce subjective soreness, thus contributing to a quicker return to baseline muscle function.

Nevertheless, findings across studies remain inconsistent. Some trials demonstrate clear reductions in CK following cryotherapy, while others report minimal or no effect (Pointon et al., 2011). This variability is likely attributable to differences in cryotherapy protocols, timing of application, and individual variability in CK response. Overreliance on cryotherapy may reduce the natural inflammatory processes that are essential for muscle remodelling and hypertrophy (Mawhinney et al., 2020).

In summary, cryotherapy may lower circulating CK levels and thereby limit immediate muscle damage markers, but its broader implications for long-term muscle adaptation remain uncertain.

Duration and Dose-Response Relationship

One of the major challenges in assessing cryotherapy lies in the variability of protocols across studies. The physiological response to cold exposure is influenced by temperature, duration, frequency and timing of application. For example, CWI is administered at 10 to 15 °C for 10-15 minutes. However, studies differ considerably in these parameters (Machado et al., 2016; Wilson et al., 2019). Evidence indicates that a dose–response effect, which means shorter exposures (<5 minutes) often fail to produce significant tissue cooling. Excessively long or repeated exposures may induce vasodilation and increase inflammation (Bleakley et al., 2012). Cryotherapy aims to reduce tissue temperature through vasoconstriction (narrowing of blood vessels). If exposure is too long, the body sometimes overcompensates with reflex vasodilation (widening of blood vessels) to protect tissues from cold damage (Charkoudian, 2010). This rush of warm blood reverses the cooling effect. Vasodilation allows more inflammatory mediators, such as histamine and cytokines, and tissue fluid to be delivered to muscle tissue (Ashina et al., 2015). Excess fluid accumulation can impair nutrient exchange and delay the clearance of waste products from the damaged area, leading to prolonged swelling (Scallan et al., 2010). This can slow down the healing process rather than accelerating it.

On another note, WBC protocols vary, ranging from one to three minutes at −110 °C to −140 °C. However, systematic reviews pinpoint that inconsistent protocols limit generalisability (Hohenauer et al., 2015). These findings indicate that optimal ‘dosing’ of cryotherapy has not been standardised, and responses may differ depending on whether the goal is acute pain relief, muscle damage attenuation, or long-term recovery enhancement.

Sex-specific Differences in Cryotherapy Response

Emerging evidence suggests that male and female athletes may respond differently to cryotherapy. For instance, hormonal factors in women, particularly fluctuations in oestrogen and progesterone, influence inflammatory and oxidative stress pathways, Therefore, potentially altering recovery dynamics (Hackney et al., 2019).

Furthermore, some studies have underlined that female athletes exhibit lower baseline CK levels post-exercise compared to males. This may reflect differences in muscle membrane stability or hormonal modulation (Stupka et al., 2001). In this context, the additional benefit of cryotherapy on CK reduction may be less pronounced in females. In comparison, other studies have indicated that females report higher subjective soreness scores post-exercise. Therefore, indicating a potentially greater perceived benefit from cryotherapy in terms of pain relief (Minett & Duffield, 2014). However, literature on sex-specific responses remains limited and often underpowered due to small sample sizes. This stresses the need for more stratified trials that explicitly compare outcomes between male and female populations.

Age-Group Differences and Response to Cryotherapy

Age plays a significant role in recovery physiology and cryotherapy outcomes. Younger athletes generally demonstrate faster regenerative capacity and lower systemic inflammation after exercise. Whereas older athletes are more prone to chronic low-grade inflammation (‘inflammaging’) and prolonged recovery times (Franceschi et al., 2018). For example, one study found that while WBC attenuated post-exercise declines in muscle torque in both age groups, younger athletes derived greater strength-preserving benefits than older ones (Haq et al., 2021). This highlights that cryotherapy may be relatively more effective for younger-trained athletes.

It is important to note that due to mixed evidence and limited sample sizes, recommendations should remain age-sensitive. This means favouring cryotherapy selectively in contexts where short-term performance and injury prevention are the priority, particularly in younger populations. For younger athletes, occasional cryotherapy may be beneficial for managing fatigue during congested competition schedules. However, routine use after every training session should be discouraged, as it may interfere with the natural inflammatory and repair processes that drive physiological improvement. This was evident in one study, which found that regular CWI after resistance training blunted long-term gains in muscle mass and strength compared to controls (Roberts et al., 2015). Another study concluded that post-exercise cryotherapy can reduce oxidative stress and inflammation acutely. In saying that, it pinpointed that this may also suppress redox-sensitive signalling required for muscle adaptation (Peake et al., 2015).

Practical Applications for Athletic Training and Clinical Recommendations

Despite variability in protocols, cryotherapy remains one of the most accessible and widely used recovery modalities in sports medicine. For practical application, localised cryotherapy is effective for targeted muscle groups, particularly in acute injury management and DOMS relief. CWI is more beneficial for systemic fatigue following whole-body exertion, such as endurance sports. On the other hand, whole-body cryotherapy may be reserved for elite athletes, with access to specialised facilities (Ihsan et al., 2021).

From a clinical standpoint, cryotherapy should be used strategically. This can include post-competition to rapidly reduce soreness and inflammation. During training cycles, cryotherapy can be used more sparingly to avoid blunting adaptation. 'Blunting adaptation' refers to a reduced or impaired ability of the body to adapt to repeated stress, particularly in the context of exercise or training. This can manifest as a plateau in performance, a decreased response to stimuli, or a decline in physical capabilities (Greig et al., 2011).

Older or recreational athletes may benefit more consistently due to reduced recovery efficiency. Younger athletes show greater strength in terms of preserving the benefits of cryotherapy. In saying that, frequent use can compromise natural recovery. Gender specific tailoring may be needed to assign as a recovery method, and further research based on evidence is needed. Thus, doctors should consider timing, frequency and athlete profile when integrating cryotherapy into recovery programs.

The Strengths and Limitations of Cryotherapy

The main advantages of cryotherapy include its accessibility, non-invasive nature and ability to provide immediate relief from soreness and swelling. The limitations include inconsistent protocols, such as the duration, temperature and frequency, potential interference with long-term adaptations and contradictory evidence regarding performance enhancement (Mawhinney et al., 2020). Furthermore, few studies highlight the outcomes according to gender and age. Thus, leaving gaps in regards to understanding the different responses of cryotherapy (Allan et al., 2022).

Gaps in Current Research

The existing literature indicates three major gaps. Firstly, it is the standardisation of protocols. The variability in cryotherapy techniques can make the comparisons difficult. Secondly, is the use of longitudinal data. Most studies focus on short-term recovery, with limited insights into chronic training outcomes. Lastly, it is population-specific evidence. This includes the fact that the research on gender-specific and age-related differences remains underexplored.

The three gaps highlight that the objectives of this review are to evaluate biochemical and physiological evidence of cryotherapy's role in accelerating recovery, addressing the advantages and limitations, and proposing directions for future research.

Methodology

Research Design

This study employed a systematic literature review model, conducting a structured review of peer-reviewed research articles, systematic reviews and meta-analyses available through academic databases. The model was selected to provide both breadth (that is, covering multiple study designs) and depth (conducting critical analysis of biochemical and performance markers). The design enabled integration of quantitative outcomes, such as changes in IL-6, CK,and ROS, with broader trends across athletic populations.

In addition, qualitative findings were examined in a complementary analysis. This included athlete-reported outcomes such as DOMS, perceived recovery speed, subjective pain relief and overall readiness to resume training. Incorporating these perspectives provided insight into how athletes experience cryotherapy beyond measurable biomarkers, and ensured that the study captured both the physiological and experiential dimensions of recovery.

Selection Criteria

The inclusion was: peer-reviewed studies in English, investigations that specifically focused on cryotherapy as a recovery intervention, measurement of biochemical, physiological, or performance outcomes, participants, observational and experimental research, and publications between 1990 to 2025. The time frame was chosen to capture both foundational research and contemporary evidence. Early 1990s studies marked the emergence of cryotherapy in sports medicine with more structured methodologies. While from the 2000s onwards, research witnessed the introduction of advanced techniques, such as whole-body cryotherapy chambers and systematic meta-analyses. Therefore, this range provided a comprehensive perspective on the evolution of cryotherapy practices and outcomes over time.

Exclusion: Studies were excluded if they were published before 1990, as early reports lacked standardised protocols and comparability with modern research. Non-English publications were also excluded to avoid translation bias and ensure consistency in interpreting the information and data. Research that focused solely on non-athletic populations (for example, dermatological or oncological applications) was not considered unless they directly related to post-exercise recovery. Additionally, studies that did not assess biochemical, physiological, or performance-related outcomes, as well as case reports, opinion piecesand anecdotal accounts, were excluded. This exclusion framework ensured that only methodologically rigorous and contextually relevant studies were included in the review.

Data Collection

Data was collected exclusively from secondary sources by using electronic databases, such as PubMed, Google Scholar, ScienceDirect, SpringerLink and a Government Website - cancer.gov

Limitations of the Methodology

This review relies exclusively on secondary data and published studies, limiting the ability to generate new experimental evidence. Publication bias may also influence results, as studies with significant findings are more likely to be published. Additionally, the variability in cryotherapy protocols complicates cross-study comparisons.

Results

Participants	**Training Intensity**	**Application**	**No. of Sessions**	**Effects**	**Reference**
12 professional tennis players (gender unspecified) (6 treated, age: 23 ± 2, BMI: 23.2 ± 1.8 $kg \cdot ms^{-2}$; 6 untreated, age 20 ± 2, BMI: 24.4 ± 1.9 $kg \cdot m^{-2}$;)	Moderate to low	WBC 3 mins −120°C	10 sessions	IL-6 increased at the end of the experiment compared to baseline Significant increase compared to control	Ziemann et al., 2012
10 top-level male rugby players (10 treated, age: 26 ± 2.5, BMI: 27.5 ± 2.3 $kg \cdot m^{-2}$;)	High	WBC 30s −60°C Then 2 mins −110°C	5 sessions	CK Decreased ~ 40% from baseline $p < 0.01$	Banfi et al., 2009

9 highly trained runners (gender unspecified) (9 treated age: 31.8 ± 6.5, BMI: 22.0 ± 2.5 2.3 kg·m^{-2};)	Moderate to high	WBC 3 mins −110°C	Post running, 24h after and 48h after	No significant difference in CK levels compared to the control Perceived pain and tiredness decreased after the first WBC session	Hausswirth et al., 2011
10 Team-sport male athletes (rugby league/union) (10 treated, age: 19.9 ± 1.1 years, BMI: 24.5 ± 2.2 kg·m^{-2};)	High	CWI 20 mins 8.9 ± 0.9°C	Post intermittent-sprint exercise	No significant effect on CK <1h, 24h and 48h after exercise Muscle torque significantly increased post-CWI compared to baseline	Pointon et al., 2012
11 Elite female synchronised swimmers (10 treated, age: 20.4 ± 0.4, BMI undisclosed)	High	WBC 3 mins −110°C	Post-training	Stable perceived fatigue with CWI compared to increased perceived fatigue in the control	Schaal et al., 2015

11 Trained male runners (11 treated, age: 20.4 ± 0.4, BMI: 22.0 ± 0.8 kg·m^{-2};)	Low	WBC 3 mins −110°C	Post, Post 24h, Post 48h, Post 72h and Post 96h	No significant change in IL-6, IL-10 IL-1β (Post 1h) and CRP (Post 24h) decreased and IL-1ra (Post 1h) increased following WBC	Pournot et al., 2011b
8\ Recreationally active males (8 treated, age: 23.6 ± 3.7, BMI: 23.3 ± 3.4 kg·m^{-2})	Moderate to high	CWI 10°C water for 10 minutes (10 x 10); 10 °C water for 30 min; (10 x 30) 20 °C water for 10 min (20 x 10) 20 °C water for 30 min (20 x 30);	Post, Post-1h, 2h, 24h, 48h	IL-6 elevated significantly from baseline in all groups Remained elevated 2h post-exercise in (20 x 30), (10 x 10) and (10 x 30) IL-6 returned to baseline concentration 24h and 48h post exercise in all conditions No difference in perceived soreness between conditions	White et al., 2014
31 Trained endurance runner males	Moderate to high	CWI: 8 °C ± 0.5 °C	1 Post	CWI had a more beneficial effect on muscle soreness 48h	(Wilson et al., 2018

(11 treated CWI, age: 41.3 ± 7.6, BMI: 24.9 ± 3.9 kg·m^{-2} 10 treated WBC, age: 37.7 ± 8.9, BMI: 22.7±2.6 kg·m^{-2})		WBC: −85°C ± 5°C followed by a 15-min warming period in an ambient room then 4-min at −85°C ± 5°C		post-treatment compared to WBC	
18 Professional male volleyball players (18 treated, age: 28.32 ± 4.01, BMI: 23.63 ± 1.12 kg·m^{-2})	Moderate to high	Each entry began with a 10 to 20 seconds adaptation Period in an open vestibule at ≈ -60°C Then, 1 to 2 minutes at -130°C	Pre-training	WBC showed statistically significant differences in IL-1β and IL-6 compared to the control group Levels of both cytokines were about twice as low after WBC exercise as compared to control exercise ($p < 0.001$).	Mila-Kierzenkowska et al., 2013

Findings and Discussion

Across the reviewed studies, both cold-water immersion (CWI) and whole-body cryotherapy (WBC) demonstrated meaningful benefits for athletes recovering from exercise. Although the outcomes varied depending on the marker measured, the population studied and the protocol that was applied. CWI consistently reduced muscle soreness within 24 to 96 hours post-exercise, with the strongest effects appearing around 48 to 72 hours. These improvements were evident even when blood markers of muscle damage, such as creatine kinase (CK), showed no significant change. This is witnessed in rugby athletes who experienced improved muscle torque after intermittent-sprint exercise despite unchanged CK levels (Pointon et al., 2012). Similarly, endurance athletes reported less soreness following CWI compared to WBC. This indicates that relatively simple and accessible methods may outperform more technologically advanced options under certain given conditions (Wilson et al., 2018).

On the other hand, WBC provided faster short-term relief. This is evident as trained runners reporting decreased pain and fatigue after the very first exposure, even though CK values were unaffected (Hausswirth et al., 2011). In addition, elite female synchronised swimmers benefitted from WBC, as they maintained stable levels of perceived fatigue, while the control group worsened (Schaal et al., 2015).

In terms of biochemical outcomes, WBC demonstrated strong anti-inflammatory effects in some cohorts. For example, professional volleyball players exhibited almost twofold lower post-exercise IL-1β and IL-6 compared to controls (Mila-Kierzenkowska et al., 2013). On another hand, a different study observed decreased CRP and IL-1β together with an increase in IL-1ra, an anti-inflammatory cytokine (Pournot et al., 2011b). It is important to note that this pattern was not universal. In professional tennis players, IL-6 was developed following WBC compared with controls (Ziemann et al., 2012). This pinpoints that cold exposure does not uniformly suppress inflammatory signalling, and that outcomes may depend heavily on protocol, exercise load and timing.

The variability in biochemical markers such as IL-6 and CK suggests that cryotherapy's effects are highly context-dependent. For instance, IL-6 levels were consistently elevated after cold-water immersion regardless of water temperature or immersion duration. However, the levels returned to baseline within 24 to 48 hours (White et al., 2014). This signifies that acute elevations in IL-6 are physiological and part of the body's adaptive response to exercise, and their suppression may not always be beneficial. Similarly, CK responses were inconsistent. While WBC reduced CK by roughly 40%in rugby players, other studies showed no difference relative to controls (Banfi et al., 2009). These findings reinforce the idea that CK is useful; however, it is an imperfect marker, and improvements in athlete function and perception of recovery often occur independently of biochemical changes.

The evidence underlines that cryotherapy reliably improves subjective recovery and muscle function, even when biochemical responses remain inconsistent. CWI appears most effective for systemic fatigue and soreness over one to four days, particularly when water temperature is ≤15 °C for 10 to 15 minutes. WBC offers rapid symptom relief and early strength preservation when applied soon after exertion. In saying that, its superiority over CWI is not consistently supported across multi-day follow-ups. Localised icing and vapocoolants remain valuable for site-specific injuries or targeted muscle soreness and complement whole-body methods when broader fatigue is present.

Furthermore, population-specific responses emerged from the evidence base. Younger trained athletes demonstrated greater strength-preserving benefits from cryotherapy, older or recreational athletes experienced reliable symptomatic relief but smaller functional improvements. On another note, female athletes may respond differently a as demonstrated by elite synchronised swimmers who benefitted from WBC in terms of fatigue control (Schaal et al., 2015). The known differences in thermoregulation, including fluctuations across the menstrual cycle, underline that protocol optimisation by gender may be warranted. Although research in this area remains limited.

Finally, the timing and frequency of cryotherapy use are critical. Early post-exercise application can yield clearer benefits. On the other hand, repeated daily use, particularly during adaptation-focused training, may blunt redox-sensitive and inflammatory signalling pathways that are needed for muscle growth and endurance improvements. In contrast, during congested competition schedules, frequent cryotherapy can be strategically deployed to maximise recovery between events. Thus, the strongest evidence points to cryotherapy as an effective short-term recovery tool that should be used selectively, with cold-water immersion offering robust medium-term benefits, and whole-body cryotherapy providing rapid relief where accessible and localised cooling is reserved for targeted injuries.

Conclusion

In conclusion, cryotherapy emerges as a valuable and context-dependent strategy for post-exercise recovery. The strongest and most consistent evidence supports cold-water immersion at temperatures around 10 to 15°C for 10 - 15 minutes, which reliably reduces muscle soreness within 24 to 96 hours. Whole-body cryotherapy can provide rapid relief and early preservation of muscle function when applied immediately after exertion. In saying that, its medium-term effects are comparable to cold-water immersion. Importantly, the biochemical evidence highlights mixed patterns: IL-6, CK and other cytokines are sometimes attenuated but not consistently so, and their suppression may not always align with improved long-term adaptations.

The findings have pinpointed that cryotherapy should be employed strategically rather than habitually. It is most useful when short-term recovery is the priority, such as during congested competition schedules or after especially demanding sessions, and less appropriate for daily use during training cycles focused on adaptation and performance gains. Localised cooling remains a practical tool for targeted injuries and soreness, complementing systemic methods, such as CWI and WBC. Ultimately, the key lies in tailoring protocols to the athlete's profile, training demands, and context. Therefore, acknowledging that younger athletes may derive greater strength-preserving benefits, while older or recreational athletes can still gain meaningful symptomatic relief.

Future research should focus on refining dose–response guidelines, standardising protocols and exploring age-gender-specific adaptations to ensure cryotherapy is used in ways that maximise benefits, without undermining long-term performance development of the athletes.

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