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CARDIOVASCULAR RESPONSES TO COLD WATER EXPOSURE: PHYSIOLOGICAL MECHANISMS, POTENTIAL BENEFITS, AND CLINICAL RISKS: A LITERATURE REVIEW

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ABSTRACT

Background: Cold water exposure (CWE), including cold water immersion, winter swimming, and cryotherapy, is increasingly used to support recovery and wellbeing. However, its cardiovascular effects remain controversial, involving both potential adaptive mechanisms and clinically relevant risks.
Objective: This review aimed to synthesize current evidence on cardiovascular responses to acute and repeated cold water exposure.
Methods: A structured search of publications from 2020–2025 was conducted using PubMed. Following screening, 20 studies were included, comprising experimental investigations, reviews, and case reports. Evidence was qualitatively analyzed with emphasis on cardiovascular outcomes and safety.
Results: Acute exposure triggers the cold shock response characterized by sympathetic activation, increases in heart rate and blood pressure, and complex autonomic modulation. Transient arrhythmias were reported in some individuals. Repeated exposure was associated with favorable changes in selected metabolic markers and improved perceived wellbeing, although findings were heterogeneous.
Conclusions: CWE induces significant cardiovascular responses with both adaptive and potentially harmful effects. Individual risk assessment and further longitudinal studies are necessary.

KEYWORDS

Cold Water Immersion, Cold Exposure, Winter Swimming, Autonomic Nervous System, Cardiovascular Risk, Arrhythmia

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Introduction

Cold water exposure (CWE) has gained substantial scientific and public interest in recent years, particularly in the context of physical performance, recovery, and overall wellbeing. Practices such as cold water immersion, winter swimming, cold showers, and cryotherapy are increasingly adopted by athletes and recreationally active individuals. These practices are often promoted as strategies to improve physiological resilience and overall health. Although voluntary cold water exposure has been practiced for centuries, especially in northern countries, its health effects remain a subject of ongoing debate. CWE encompasses a wide range of interventions differing markedly in temperature, duration, body surface area exposed, and physiological load, which complicates direct comparison across studies. Current evidence indicates a coexistence of potential physiological benefits and measurable cardiovascular risks. Both appear to depend strongly on individual characteristics and exposure conditions. (Espeland et al. 2022).

CWE represents a potent physiological stressor that provokes rapid and coordinated responses across multiple regulatory systems. The cardiovascular and autonomic nervous systems play a central role in these responses. Acute exposure typically induces peripheral vasoconstriction, changes in heart rate and blood pressure, and activation of thermoregulatory mechanisms aimed at preserving core temperature. These responses are primarily mediated by the autonomic reflexes (Jdidi et al. 2024). Because of its pronounced cardiovascular effects, CWE is frequently used as an experimental model to study cardiovascular adaptability under acute stress. At the same time, repeated exposure may promote adaptive processes that could support autonomic regulation and cardiovascular efficiency (Tóth et al. 2024). However, such adaptations appear variable and are not consistently observed across studies.

Despite growing interest in potential benefits, CWE may pose clinically relevant risks. Acute cold exposure can provoke exaggerated hemodynamic responses and trigger cardiac arrhythmias, particularly in individuals with pre-existing cardiovascular disease or limited cold acclimatization. These risks highlight the importance of careful evaluation of cardiovascular safety when cold water interventions are considered. (Lundström et al. 2025).

Objective of the Article

The aim of this narrative review is to critically summarize and evaluate current evidence on cardiovascular responses to cold water exposure. The review focuses on underlying physiological mechanisms, potential health and performance benefits, and clinically relevant risks associated with both acute and repeated cold exposure. Based on available evidence, cold water exposure appears to induce measurable cardiovascular and metabolic adaptations that may reflect autonomic regulation and cardiovascular efficiency in healthy individuals. At the same time, it poses identifiable risks for individuals with pre-existing cardiovascular conditions. By integrating findings from experimental studies, observational research, and case reports, this review provides an evidence based perspective to inform future research, support safe practice guidelines, and guide the clinical application of cold water interventions in sports and medicine.

Methodology

This narrative review was developed through a structured literature search of scientific publications published between 2020 and 2025. Although a structured search strategy was applied, this review does not follow formal systematic review methodology (e.g., PRISMA), and no quantitative synthesis or risk-of-bias assessment was performed. The aim was to identify recent evidence on cardiovascular responses to cold water exposure, including underlying physiological mechanisms, potential benefits, and clinical risks. The search was conducted between November and December 2025 using the PubMed database and included the following keywords: *cold water immersion, winter swimming, ice bath, cold exposure, cardiovascular, heart rate, heart rate variability, blood pressure, autonomic nervous system, cold shock, arrhythmia, cardiovascular risk, adaptation, mood, wellbeing,* and *recovery*. Only peer-reviewed articles published in English were considered.

Titles and abstracts were screened to exclude opinion articles, conference abstracts, incomplete reports, and studies not directly addressing cardiovascular responses to cold exposure. Full-text articles were then assessed according to predefined inclusion criteria, with emphasis on physiological mechanisms, potential benefits, and clinically relevant risks.

The final synthesis included 20 publications comprising randomized controlled trials, systematic reviews, meta-analyses, high-quality narrative reviews, and case reports. Studies were critically appraised and qualitatively synthesized, with a focus on cardiovascular outcomes, safety considerations, and clinical relevance.

Limitations of the Review

This review has a narrative design, which precludes formal statistical analysis and introduces the potential for subjective selection and interpretation of evidence. Only articles identified through predefined sources were included, which may have limited the scope of the literature search. In addition, the reviewed studies were heterogeneous with respect to participant age, sex, health status, and cold exposure protocols, limiting the generalizability of the findings.

Several included studies were small experimental investigations that, although mechanistically informative, may not reflect cardiovascular responses at the population level. Finally, because this review does not follow a systematic methodology, there is an inherent risk of selection bias. The conclusions should therefore be interpreted as exploratory and hypothesis-generating rather than definitive.

Results

Acute cardiovascular responses to cold water exposure

Acute exposure to cold water induces rapid cardiovascular responses collectively referred to as the cold shock response. This reaction is primarily mediated by sudden activation of the sympathetic nervous system, resulting in marked increases in heart rate and blood pressure, often accompanied by hyperventilation (Jdidi et al. 2024). Simultaneously, peripheral vasoconstriction develops to preserve core temperature and maintain adequate perfusion of vital organs (Tsoutsoubi et al. 2022). These immediate physiological adjustments play a key role in maintaining homeostasis during acute cold stress (Knechtle et al. 2020; Jdidi et al. 2024). For clinicians understanding these early cardiovascular reactions is essential, as they underpin both adaptive mechanisms and potential cardiovascular risks.

In addition to changes in heart rate and blood pressure, acute cold water exposure elicits pronounced hemodynamic and vascular responses. Peripheral vasoconstriction represents a primary mechanism for redistributing blood flow from the skin and extremities toward central organs, thereby increasing systemic vascular resistance and arterial pressure immediately upon immersion (Reed et al. 2023; Jdidi et al. 2024).

These responses are predominantly mediated by rapid sympathetic activation and reflect an integrated cardiovascular adjustment to sudden thermal stress.

Despite the predominance of vasoconstriction, cold-induced vasodilation (CIVD) may occur in distal extremities such as the fingers and toes, manifesting as short, cyclic increases in blood flow. CIVD is thought to protect peripheral tissues from cold injury and preserve local function during exposure (Tsoutsoubi et al. 2022; Yasukochi et al. 2023). The magnitude and timing of CIVD are influenced by individual factors, including sex, age, prior cold exposure, and genetic variability (Tsoutsoubi et al. 2022).

These vascular adjustments are closely linked to immediate cardiac responses, including transient increases in stroke volume and cardiac output that support systemic circulation under acute cold stress (Reed et al. 2023; Jdidi et al. 2024). Understanding the interaction between vasoconstriction, CIVD, and autonomic regulation is essential for interpreting both adaptive cardiovascular mechanisms and potential adverse responses associated with cold water exposure.

One key study examining acute heart rate responses was conducted by Malinowski et al. (2023), who investigated cardiovascular effects of cold-water facial immersion combined with apnea. The authors demonstrated a rapid and pronounced decrease in heart rate, reflecting activation of the diving reflex and enhanced parasympathetic modulation. This bradycardic response occurred shortly after exposure and exhibited considerable interindividual variability, influenced by baseline heart rate and autonomic tone. These findings underscore the importance of autonomic control in shaping immediate cardiac responses to cold water exposure. However, heart rate changes represent only one component of the cardiovascular response, as autonomic regulation also involves complex modulation of heart rate variability.

Heart rate variability (HRV) is widely used to assess autonomic modulation of cardiac function and reflects the balance between sympathetic and parasympathetic activity. Knežević et al. (2025) examined the effects of cold water intake on HRV in healthy young women, providing insight into autonomic responses to mild systemic cold stimulation distinct from whole-body immersion. Significant alterations were observed in both time and frequency domain HRV indices, indicating rapid changes in autonomic regulation. Importantly, the observed patterns suggested simultaneous activation of both autonomic branches, highlighting the dynamic and non-linear nature of cardiovascular responses to cold exposure. Although the thermal stimulus was relatively mild, the findings demonstrate the sensitivity of cardiac autonomic control to even limited cold challenges. Comparable reflex-mediated autonomic and vascular modulation has also been reported following cold-related auricular stimulation, further supporting the role of reflex pathways in shaping cardiovascular responses (Sagui et al., 2024).

Acute cold water exposure therefore involves rapid and complex cardiovascular adjustments. In extreme cold-water conditions, experienced divers exhibit short-term modulation of HRV, reflecting coordinated autonomic responses during immersion (Lundell et al. 2021). As described above, immersion triggers a cold shock response characterized by sympathetic activation, peripheral vasoconstriction, and, in distal extremities, CIVD (Tsoutsoubi et al. 2022; Reed et al. 2023; Jdidi et al. 2024). Cold facial immersion activates the diving reflex, inducing parasympathetic-mediated bradycardia with marked individual variability (Malinowski et al. 2023). Even mild systemic cold stimulus, such as cold water ingestion, can rapidly alter autonomic cardiac control, resulting in concurrent sympathetic and parasympathetic activation as reflected by HRV indices.

Lundström et al. (2025) extended these findings by examining healthy adolescents exposed to acute cold water immersion, including both facial and full-body exposure to ice-cold water. Continuous ECG monitoring revealed rapid and pronounced increases in heart rate immediately upon immersion, with responses generally more pronounced during full-body exposure. Notably, transient arrhythmias, including supraventricular extrasystoles and ventricular bigeminy, were observed in a subset of participants, highlighting the acute cardiovascular stress imposed by sudden cold exposure. Although the small sample size limits generalizability, these findings emphasize substantial interindividual variability and the dynamic nature of cardiac responses during brief cold water immersion.

Taken together, the available evidence indicates that acute cold water exposure elicits multifaceted cardiovascular responses involving rapid autonomic, hemodynamic, and electrophysiological adjustments. While these responses may reflect adaptive mechanisms, they also reveal potential risks, particularly in susceptible individuals. These observations highlight important areas for future research, including identification of predictors of adverse responses, optimization of exposure protocols, and evaluation of long-term cardiovascular consequences.

Long-term cardiovascular adaptations from repeated exposure

Several studies suggest that repeated cold water exposure can lead to long-term physiological adaptations with potential relevance for cardiovascular health. Teległów et al. (2024) investigated the effects of regular winter swimming on blood morphological and biochemical parameters, as well as antioxidant enzyme activity, in healthy males. The authors reported favorable changes in blood rheology and oxidative stress markers, indicating improved oxygen transport efficiency and enhanced antioxidative capacity. Although direct measures of autonomic function were not assessed, these findings suggest systemic adaptations that may support cardiovascular stability during repeated cold exposure.

Ptaszek et al. (2023) examined the effects of whole-body cryotherapy and winter swimming on lipid profile parameters and selected adipokines in physically active adults. The study demonstrated that regular whole-body cryotherapy was associated with changes in lipid profiles and selected adipokines in men, while regular winter swimming influenced adipokine levels in both women and men. Importantly, these effects were observed in individuals without underlying cardiovascular disease, indicating that repeated cold exposure may modulate metabolic parameters even in healthy populations. The authors emphasized that the magnitude and direction of these changes depended on the type and frequency of cold exposure.

Versteeg et al. (2023) explored the effects of a three-week repeated cold water immersion protocol on cardiovascular and immune parameters in healthy adults. The authors observed modest, subclinical changes in heart rate and blood pressure responses, along with alterations in leukocyte counts, suggesting that even short-term repeated cold exposure constitutes a measurable physiological stressor. Although these effects were not clinically significant, they may contribute to adaptive cardiovascular and immune processes over time.

Further evidence was provided by Tóth et al. (2024), who investigated the impact of regular cold water immersion on markers of subclinical atherosclerosis, inflammatory parameters, body fat distribution, and lipid profiles in healthy volunteers. The study reported favorable

changes in selected lipid parameters and markers associated with subclinical atherosclerosis, suggesting favorable changes in markers associated with cardiovascular risk. Additionally, alterations in inflammatory markers and fat accumulation were observed, indicating that repeated cold exposure may influence metabolic and inflammatory pathways relevant to cardiovascular health. Importantly, these findings were limited to subclinical markers and do not imply direct protection against overt cardiovascular disease.

Overall, the available evidence suggests that repeated cold water exposure is associated with a range of long-term physiological adaptations that may influence cardiovascular-related metabolic, inflammatory, and hematological parameters. However, most studies involve small sample sizes and rely on surrogate outcomes rather than clinical endpoints. Consequently, further well-designed, long-term studies are required to clarify the magnitude, mechanisms, and clinical relevance of these adaptations.

Potential benefits for performance and wellbeing

Cain et al. (2025) conducted a systematic review and meta-analysis evaluating the effects of cold water immersion on health and wellbeing outcomes in adults. The authors reported that repeated cold water exposure was associated with improvements in self-reported wellbeing, mood, and perceived stress in several studies. Although cardiovascular endpoints were not the primary focus, the reviewed interventions imposed repeated physiological stress in which cardiovascular and autonomic regulation play a central role. The authors highlighted substantial heterogeneity in exposure protocols, participant characteristics, and outcome measures, which limits direct comparisons between studies and precludes firm conclusions regarding underlying mechanisms. Nevertheless, the observed improvements in wellbeing and stress perception suggest that repeated cold water immersion may influence systemic stress regulation, a process closely linked to cardiovascular and autonomic function.

Cold water swimming is increasingly practiced as a form of regular cold exposure and has been discussed in the literature in relation to both potential health benefits and cardiovascular risks. In their narrative review, Knechtle et al. (2020) summarized existing evidence on cold water swimming, emphasizing its growing popularity among recreationally active individuals and athletes. The authors reported that repeated cold exposure may influence cardiovascular regulation through adaptations of the autonomic nervous system, including changes in heart rate and blood pressure responses, although the available evidence remains heterogeneous. Importantly, Knechtle et al. noted that while some individuals may develop improved tolerance to cold-induced cardiovascular stress, acute exposure is associated with marked increases in heart rate and blood pressure, particularly in unacclimatized individuals. The review further emphasized that cardiovascular responses to cold water swimming are highly dependent on individual factors such as age, health status, cardiovascular disease, and prior cold exposure.

Although Ptaszek et al. (2023) focused primarily on metabolic outcomes, the reported changes in lipid profile parameters and adipokines may have indirect relevance for cardiovascular health, given their established role in cardiovascular risk modulation (Farkhondeh et al. 2020). Similarly, Tóth et al. (2024) reported improvements in markers of subclinical atherosclerosis, lipid parameters, and inflammatory profiles following repeated cold water exposure. While these findings reflect early physiological adaptations rather than direct clinical outcomes, they provide additional context for potential long-term cardiovascular effects of regular cold water immersion.

In contrast, Teległów et al. (2024) observed no significant changes in several haematological parameters following regular winter swimming in healthy males. These findings indicate that not all cardiovascular- or metabolism-related markers are consistently influenced by repeated cold exposure, highlighting variability in physiological responses depending on the parameters assessed and exposure characteristics. Overall, the available evidence suggests that potential benefits for performance and wellbeing are heterogeneous and context dependent, underscoring the need for further research to clarify which outcomes reliably reflect meaningful cardiovascular and systemic adaptations.

Clinical risks

Acute cold water exposure may pose clinically relevant cardiovascular risks, particularly in individuals with pre-existing heart disease or limited cold acclimatization. Sudden immersion in cold water triggers rapid sympathetic activation, leading to marked increases in heart rate, blood pressure, and vascular resistance (Reed et al. 2023; Jdidi et al. 2024). Sex-specific differences have been reported, with women demonstrating higher heart rate responses and, in some cases, greater mean arterial pressure during cold water immersion, suggesting that individual characteristics may modulate cardiovascular strain (Tsoutsoubi et al. 2022).

Studies involving full-body immersion in ice-cold water have documented transient arrhythmias, including supraventricular extrasystoles and ventricular bigeminy, in a subset of otherwise healthy participants, highlighting the acute cardiac stress imposed by sudden cold exposure (Lundström et al. 2025). Although such events are generally self-limiting, they underscore that cold water exposure is not physiologically neutral, even in young and physically active populations.

Rare but clinically significant adverse events have also been reported. Scarfò et al. (2021) described a case of paroxysmal atrial fibrillation triggered by ice-cold water ingestion in a triathlete. Experimental reproduction of the exposure confirmed that the arrhythmia occurred exclusively following cold water intake, supporting a causal association between acute cold stimulation and cardiac rhythm disturbance in susceptible individuals.

Beyond acute events, observational data suggest that frequent or repeated cold water exposure may be associated with subclinical cardiovascular stress. Jurczak et al. (2025) reported that winter swimming performed more than once per week was associated with a reduction in autonomic reserve, a finding that may reflect diminished cardiovascular adaptability and increased vulnerability to stress.

Faivre-Rampant et al. (2024) evaluated cardiac electrical and functional responses in athletes following an outdoor cold water swimming event. The study demonstrated transient QTc interval prolongation and subtle, reversible changes in cardiac function immediately after exposure, although no arrhythmias were observed. The authors concluded that acute cold water immersion can impose measurable, albeit generally well-tolerated, electrophysiological stress on the heart, even in trained individuals. The potential clinical implications of QTc prolongation, particularly in the context of autonomic modulation during cold exposure, warrant further investigation.

In summary, while cold water exposure may confer certain physiological benefits, it is associated with measurable cardiovascular risks. Acute exposure can provoke rapid hemodynamic changes and transient arrhythmias, whereas frequent or repeated exposure may subtly alter autonomic regulation. These findings support the need for individualized risk assessment, cautious implementation, and appropriate monitoring when cold water interventions are considered.

Discussion

This narrative review synthesizes contemporary evidence on cardiovascular responses to cold water exposure, emphasizing the complex interaction between autonomic regulation, vascular responses, adaptive mechanisms, and clinically relevant risks. The available literature indicates that cardiovascular effects of cold water exposure cannot be interpreted as uniformly beneficial or harmful but are highly context dependent, varying according to exposure characteristics and individual susceptibility.

A consistent finding across experimental studies is that acute cold water exposure elicits an immediate cold shock response characterized by sympathetic activation, peripheral vasoconstriction, and marked increases in heart rate and blood pressure (Reed et al. 2023; Jdidi et al. 2024). However, the evidence also demonstrates that this response is not exclusively sympathetic. Cold facial immersion and apnea activate the diving reflex, resulting in pronounced parasympathetic-mediated bradycardia (Malinowski et al. 2023), while changes in heart rate variability indicate concurrent activation of both autonomic branches (Knežević et al. 2025). These findings challenge simplified interpretations of cold exposure as a purely sympathetic stressor and highlight the finely balanced autonomic adjustments that support cardiovascular homeostasis during acute thermal stress. Nevertheless, substantial interindividual variability observed across studies underscores an important gap in identifying predictors of exaggerated or maladaptive responses, particularly in unacclimatized individuals.

Evidence from repeated or regular cold water exposure suggests the presence of adaptive processes affecting cardiovascular-related parameters, although their clinical significance remains uncertain. Studies of winter swimming and repeated immersion report favorable changes in blood rheology, oxidative stress markers, lipid profiles, adipokines, and selected inflammatory indices (Ptaszek et al. 2023; Teległów et al. 2024; Tóth et al. 2024). These findings indicate potential improvements in cardiovascular resilience and metabolic regulation. However, most reported effects involve surrogate or subclinical markers rather than hard cardiovascular outcomes.

Short-term intervention studies further suggest that repeated cold water exposure constitutes a measurable physiological stressor. Versteeg et al. (2023) demonstrated modest alterations in cardiovascular and immune parameters following a brief repeated exposure protocol, supporting the concept that adaptive processes may arise in response to repeated thermal stress. At the same time, inconsistent findings across studies, including the absence of significant changes in selected hematological markers (Teległów et al. 2024), highlight marked heterogeneity in physiological responses. This variability underscores the need for standardized exposure protocols, larger sample sizes, and longer follow-up periods to clarify the magnitude and durability of observed adaptations.

Beyond physiological markers, repeated cold water exposure has been associated with improvements in self-reported wellbeing, mood, and perceived stress (Cain et al. 2025). Although these outcomes are not direct cardiovascular endpoints, they are closely linked to autonomic and stress-regulatory systems that influence cardiovascular function. Nevertheless, substantial heterogeneity in study design and outcome measures limits mechanistic interpretation and precludes definitive conclusions regarding causality.

Despite growing enthusiasm for cold water practices, the reviewed literature clearly demonstrates the presence of cardiovascular risks. Acute immersion may provoke excessive sympathetic responses, transient arrhythmias, and marked hemodynamic stress, even in healthy individuals (Lundström et al. 2025). Case reports further indicate that clinically significant arrhythmias can occur following cold exposure in susceptible individuals (Scarfò et al. 2021). Additionally, transient QTc prolongation observed after outdoor cold water swimming suggests that electrophysiological stress may occur even in trained athletes (Faivre-Rampant et al. 2024). Importantly, the majority of reported arrhythmias were transient and self-limiting, and no serious adverse cardiac events were documented in the reviewed experimental studies. In extreme conditions, exaggerated cold shock responses may impair breathing control and increase the risk of secondary drowning, indirectly contributing to cardiovascular risk.

Repeated exposure may also influence autonomic reserve, as suggested by observational findings linking frequent winter swimming with reduced autonomic capacity (Jurczak et al. 2025). Collectively, these data emphasize that cold water exposure should not be regarded as universally safe and highlight the importance of individualized risk assessment, particularly in individuals with underlying cardiovascular disease or limited cold acclimatization.

By integrating evidence from experimental studies, observational research, systematic reviews, and case reports, this narrative review provides a comprehensive and clinically oriented synthesis of cardiovascular responses to cold water exposure. Its strength lies in the balanced presentation of potential benefits and risks, with emphasis on physiological mechanisms and clinical relevance. Key gaps in the literature include the lack of large-scale longitudinal studies, limited data on vulnerable populations, inconsistent exposure protocols, and absence of standardized cardiovascular outcome measures. Future research should aim to define safe exposure thresholds, identify predictors of adverse responses, and determine whether observed subclinical adaptations translate into meaningful long-term cardiovascular benefits.

Conclusions

Cold water exposure elicits pronounced cardiovascular and autonomic responses that are highly dependent on exposure type and individual susceptibility. Repeated exposure may confer favorable subclinical adaptations in healthy, acclimatized individuals, but acute immersion can provoke substantial hemodynamic and electrophysiological stress, even in athletes. Cold water interventions should be implemented progressively, with careful cardiovascular screening, and should not be considered universally safe or evidence-based for performance enhancement or health promotion until stronger, long-term clinical outcome data are available.

Disclosure

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