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# Systemic Cryotherapy and Its Effects on the Cardiovascular and Autonomic Nervous Systems in the Context of Post-Exercise Recovery - A Narrative Review of the Literature

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## Abstract

Systemic cryotherapy involves brief exposure of the whole body to extremely low temperatures, usually in a cryochamber or cryosauna. It is increasingly used in medicine and sport, particularly due to its potential effects on the cardiovascular system, autonomic regulation and post-exercise recovery. This review aimed to summarise current knowledge regarding physiological responses to whole-body cryotherapy, with emphasis on circulatory and autonomic nervous system changes and their relevance to recovery.

This narrative review analysed experimental, interventional and observational studies identified in the PubMed, Scopus and Web of Science databases. Exposure to extreme cold induces rapid thermoregulatory, haemodynamic and neurohormonal responses, including peripheral vasoconstriction, central blood volume redistribution, transient blood pressure and heart rate changes, and modulation of autonomic nervous system activity. Some studies observed increased parasympathetic activity after treatment; however, their magnitude and duration depended on the protocol, study population and timing of assessment.

Available evidence suggests that systemic cryotherapy may reduce subjective fatigue and muscle soreness after exercise, whereas its effects on objective recovery markers, muscle damage and performance remain inconclusive. Interpretation is limited by small sample sizes, heterogeneous exposure protocols and insufficient methodological standardisation. Systemic cryotherapy may complement recovery strategies; however, further research is needed to confirm its efficacy and safety.

**Keywords:** systemic cryotherapy; cardiovascular system; autonomic regulation; heart rate variability; post-exercise recovery;

## Introduction

In recent years, there has been a marked increase in interest in regenerative methods based on controlled exposure of the body to extreme temperatures. One such method is whole-body cryotherapy, which involves brief exposure to an environment with very low temperatures, typically ranging from around –110 to –160°C. This method was initially used primarily in rehabilitation medicine, particularly in the treatment of rheumatic diseases and selected musculoskeletal conditions. Over time, its application began to extend beyond the clinical context, and cryotherapy also found a place in sport, where it came to be regarded as one of the methods to aid post-exercise recovery.

The development of training and wellness facilities has meant that cryogenic chambers are no longer available exclusively in specialised medical centres. They can now also be found in some sports, rehabilitation and wellness centres. In practice, cryotherapy is often incorporated into broader recovery programmes, alongside massage, hydrotherapy, saunas and recovery training. The increased availability of this method has led to interest from various user groups — ranging from elite athletes to physically active individuals and patients undergoing treatments to support medical care or improve functional fitness.

However, the growing popularity of cryotherapy does not mean that its effects have been unequivocally confirmed in all areas of application. Particular interest is focused on the impact of extreme cold on the cardiovascular system and autonomic regulatory mechanisms. Exposure to very low temperatures constitutes a strong physiological stimulus that triggers a series of adaptive responses, including changes in blood vessel tone, blood distribution, heart rate, blood pressure and the activity of the autonomic nervous system. For this reason, the question of safety and the potential benefits of such an intervention is of significant importance in both medicine and sports practice.

In the sporting environment, systemic cryotherapy is often viewed as a method capable of accelerating recovery following intense exercise. It is assumed that exposure to cold may reduce the severity of muscle pain, modulate the inflammatory response and facilitate a return to subsequent training sessions. At the same time, in popular discourse, these benefits are sometimes presented too simplistically, whilst the body's actual responses are more complex, and research findings are not always consistent. This applies in particular to the effect of cryotherapy on performance indicators and markers of muscle damage, where, alongside studies demonstrating beneficial effects, there are also studies that do not confirm a clear advantage of this method over other recovery strategies or over passive recovery.

From a physiological point of view, exposure to extremely low temperatures leads to the rapid activation of thermoregulatory and circulatory mechanisms. This primarily results in peripheral vasoconstriction, a reduction in cutaneous blood flow, and a relative shift of blood volume towards the central parts of the circulatory system. These changes activate cardiovascular reflexes and may influence the balance between the sympathetic and parasympathetic divisions of the autonomic nervous system. In studies assessing heart rate variability and baroreceptor sensitivity, an increase in parameters suggesting heightened parasympathetic activity has been described following cryostimulation; however, these effects are not observed to the same extent in all study groups.

From the perspective of exercise physiology, it is particularly interesting to determine whether the reactions described above can actually translate into more efficient recovery of the body

following exercise. Current data suggest that cryotherapy may have a beneficial effect on the subjective perception of muscle soreness and certain neurovegetative indicators, but its impact on objective recovery parameters remains less clear. The difficulty in interpretation stems, among other things, from the wide variety of protocols used — covering temperature, exposure time, number of sessions, timing of application after exercise, and the nature of the exercise itself — as well as from the heterogeneity of the study populations.

The issue of safety is also significant. Although systemic cryotherapy is generally considered well-tolerated in appropriately selected individuals, the literature also describes adverse effects and situations in which the use of this method requires particular caution or is contraindicated. This applies in particular to individuals with uncontrolled hypertension, unstable cardiovascular diseases, certain neurological conditions, or impaired cold tolerance. For this reason, safety assessment should form an integral part of the pre-treatment screening process.

In view of these discrepancies, it seems appropriate to organise the available data and provide a concise overview of the physiological basis of systemic cryotherapy. Particular attention should be paid to the mechanisms responsible for changes within the circulatory system and the autonomic regulation of cardiac function, as these may partly explain the observed regenerative effects and, at the same time, remain crucial from the point of view of the safety of this method.

The aim of this study is to present the current state of knowledge regarding the effects of systemic cryotherapy on the cardiovascular and autonomic nervous systems, as well as to discuss the possible significance of these phenomena for post-exercise recovery. This article is a narrative review and is based on an analysis of available experimental and observational studies. Its aim is not to formulate definitive practical recommendations, but to organise the most important issues and identify areas that still require further, better-standardised research.

**Methods of literature selection**

This study is a narrative review and focuses on the current state of knowledge regarding the effects of systemic cryotherapy on the cardiovascular system, autonomic regulation, and post-exercise recovery processes. A qualitative approach was adopted in this study, allowing for a broader perspective not only on the research findings themselves, but also on the physiological mechanisms and practical significance of the observed effects.

The literature review was based on searches of the PubMed, Scopus and Web of Science databases. The search utilised keywords related to whole-body cryotherapy, cold exposure, cardiovascular responses, autonomic regulation and post-exercise recovery, including: whole-body cryotherapy, whole-body cryostimulation, cold exposure, cardiovascular responses, heart rate variability, autonomic regulation, post-exercise recovery and athletes. The review primarily included publications from the last two decades, though older studies were also considered where justified, provided they were significant for understanding the physiology of the body's response to cold.

The analysis mainly included experimental, interventional and observational studies concerning haemodynamic changes, autonomic responses and post-exercise recovery. Selected review articles and conceptual studies were also used to supplement the analysis where they helped to better organise the issues discussed or place them within a broader physiological context. Particular attention was paid to differences between the research protocols used, especially

regarding exposure temperature, duration of the procedure, number of sessions, and characteristics of the study populations.

Due to the narrative nature of the work, no formal assessment of the risk of systematic error or quantitative analysis was carried out. The emphasis was placed primarily on the consistency of the conclusions, the methodological quality of the included studies, and the most significant limitations of the available data, such as small sample sizes, the lack of full standardisation of protocols, and the heterogeneity of the study groups.

## 3. The body's response to extreme cold – a physiological perspective

In order to properly assess the potential impact of systemic cryotherapy on recovery and the cardiovascular system, it is necessary to first discuss the basic physiological mechanisms triggered in response to cold. Exposure of the body to extremely low temperatures constitutes a powerful environmental stimulus that activates a series of complex adaptive responses aimed at maintaining homeostasis.[1–3] In the case of systemic cryotherapy, where the temperature in cryogenic chambers typically ranges from approximately –110°C to –160°C, this response occurs very rapidly and involves several physiological systems simultaneously.[2,4,5] The most important of these relate to thermoregulation, the circulatory system, and neurohormonal mechanisms associated with the stress response.[1,2,5] The response to cold is therefore not limited solely to the skin surface, but is systemic in nature.

From the perspective of exercise physiology and sports medicine, it is also significant that the response to cold involves both immediate mechanisms, occurring within the first few seconds of exposure, and adaptive processes that develop with repeated exposure to the stimulus.[5,6] Understanding these phenomena is of great importance for assessing the potential benefits and risks associated with the use of systemic cryotherapy, particularly in the context of its impact on the cardiovascular system and post-exercise recovery mechanisms.

### 3.1. Mechanisms for maintaining the body's thermal balance

The body's primary task when exposed to cold is to maintain a relatively constant core temperature.[3,7] This process is controlled by the thermoregulatory system, the central component of which is the hypothalamus.[3,7] It integrates information from thermal receptors present both in the skin and in deeper tissues, and then activates the appropriate effector mechanisms.[3,7]

In the event of sudden exposure to very low temperatures, the first line of defence consists of cold receptors located in the skin.[3,7] Their stimulation leads to the rapid transmission of signals to regulatory centres in the central nervous system. In response, mechanisms limiting heat loss are activated. One of the most important is the reduction of blood flow through peripheral tissues, which limits heat exchange between the body and the external environment[3,7]

In addition to vascular mechanisms, metabolic processes also play a significant role.[3,7] Under conditions of prolonged cold, the body can increase heat production through increased metabolism, shivering and other forms of thermogenesis.[3,7] In the case of short-term exposure to extreme cold, typical of systemic cryotherapy, rapid vascular and autonomic responses predominate, whilst the contribution of slower-developing metabolic mechanisms is smaller.[1,2,5]

The subjective sensation of cold also remains an important element of the thermoregulatory response.[3,7] Signals from skin receptors trigger characteristic sensory sensations, which may lead to reflex reactions such as increased muscle tone or changes in breathing patterns. [3,7] These reactions form part of the body's overall response to cold, although under conditions of whole-body cryotherapy they are usually limited due to the short duration of exposure and controlled environmental conditions.

### 3.2. Changes in blood flow and peripheral vascular pressure

One of the most significant consequences of the activation of thermoregulatory mechanisms is the rapid constriction of blood vessels in the skin and peripheral tissues.[1-3,8] This phenomenon, known as vasoconstriction, is the primary mechanism limiting heat loss. Vasoconstriction leads to a reduction in blood flow through the superficial layers of the skin, thereby limiting heat exchange between the body and the environment.

The consequence of this process is the displacement of part of the blood volume from peripheral areas to the central parts of the circulatory system.[3,8,9] This phenomenon is described as centralisation of circulation. In practice, it may increase venous return to the heart and temporarily alter haemodynamic conditions.

These changes affect haemodynamic parameters, primarily arterial pressure, which often temporarily rises during exposure to cold.[1,4,5,8] The heart rate response is often more complex: in the acute phase, a reaction associated with sympathetic activation may occur, whilst following exposure, many studies have also observed features of increased parasympathetic activity, evident in heart rate variability analysis.[5,6,10]

It is worth noting that the reactions described are usually transient and, in healthy individuals, subside shortly after the end of exposure.[1,2,8] Upon leaving the cryogenic chamber, there is a gradual dilation of peripheral vessels and a redistribution of blood to peripheral tissues. This may be accompanied by a sensation of warmth following the procedure.

From the perspective of exercise physiology, changes in blood distribution and peripheral vascular tone may be significant for the regenerative processes occurring in skeletal muscles. Vasoconstriction during cold exposure may temporarily restrict blood flow in exercise-loaded tissues, whilst the subsequent redistribution of perfusion may influence the removal of metabolites and the delivery of oxygen and energy substrates. This mechanism is often cited as one of the possible explanations for the effects of cryotherapy, although its actual significance for recovery remains a matter of debate.[11-13]

### 3.3. The effect of cold on the endocrine system and the stress response

However, the body's response to cold is not limited to vascular and thermoregulatory changes. Exposure to extreme cold also activates neurohormonal mechanisms associated with the stress response.[1,2,5] The cold stimulus is interpreted by the nervous system as a challenge to homeostasis, leading to activation of the sympathetic branch of the autonomic nervous system and potentially involving the hypothalamic–pituitary–adrenal axis.[1,5,14]

One of the better-documented effects of this response is increased secretion of catecholamines, particularly noradrenaline.[5,6,14] These compounds play a significant role in regulating the

body's response to stress, influencing blood vessel tone, the mobilisation of energy substrates, and the body's overall readiness for action. In the context of whole-body cryotherapy, the increase in catecholamine concentrations may partly explain the observed haemodynamic changes.[5,6,14]

Changes in cortisol levels have also been reported in response to cold, although the results in this regard are less consistent.[6,14] Not all studies confirm a significant increase in cortisol levels following cryotherapy, and the observed effects may depend on the number of exposures, the timing of sample collection, and the characteristics of the study group. For this reason, the effect of systemic cryotherapy on the hypothalamic–pituitary–adrenal axis should be interpreted with caution.

It is also worth noting the potential impact of cold exposure on the immune system and inflammatory processes. Some studies suggest changes in the concentrations of selected pro-inflammatory and anti-inflammatory cytokines; however, the direction and magnitude of these changes are not entirely clear.[6,14-16] These likely depend on numerous factors, such as the exposure protocol, the baseline condition of the subjects, the intensity of exercise preceding the procedure, or the number of sessions.

From the perspective of adaptive physiology, it is also significant that repeated exposure to cold may lead to a gradual modulation of the stress response.[5,6] In some studies, the phenomenon of habituation was observed, involving a weakening of certain responses with repeated exposure to the same stimulus.[5,6] This may indicate the body's ability to adapt to environmental conditions, although the extent of these changes and their practical significance still require further investigation.

## 4. The effects of systemic cryotherapy on the circulatory system

The cardiovascular system is one of the most important physiological systems that responds to sudden changes in ambient temperature. In the case of whole-body cryotherapy, the body is subjected to short-term exposure to extremely low temperatures, which triggers a rapid haemodynamic response involving changes in blood vessel tone, blood distribution and cardiac function parameters.[1,2,4,5] These responses are primarily adaptive in nature and serve to limit heat loss, maintain internal environmental stability, and preserve adequate perfusion of central organs.[1,2,8]

From the perspective of circulatory physiology, cold acts as a powerful stimulus that activates both neural and humoral mechanisms responsible for regulating blood vessel tone.[1–3,8] Consequently, changes occur in vascular resistance and blood flow through various parts of the body. Parameters such as blood pressure, heart rate, and stroke volume may also be affected.[1,4,8] The severity of these reactions, however, depends on many factors, including the temperature in the cryogenic chamber, the duration of exposure, individual sensitivity to cold, and the general health of the person undergoing the procedure.[1,2,5]

The literature emphasises that the cardiovascular response to extreme cold can be both acute, occurring immediately during exposure, and partially adaptive, developing with repeated exposure to the stimulus.[5,6,8] Distinguishing between these two aspects is important as it allows for a better assessment of the potential significance of systemic cryotherapy both in terms of cardiovascular safety and its possible impact on post-exercise recovery.[5,13,17]

### 4.1. Immediate haemodynamic changes during exposure to cold

Entering a cryochamber involves a sudden thermal stimulus, which rapidly activates the mechanisms regulating blood vessel tone.[1,2,8] One of the first responses is vasoconstriction within the skin and peripheral tissues, leading to an increase in vascular resistance.[1-3,8] This process limits heat loss and helps to maintain the temperature of the body's core structures.

Following vasoconstriction, part of the blood volume shifts from peripheral areas to the central circulation.[3,8,9] Increased venous return may affect cardiac filling, thereby modifying stroke volume and the working conditions of the heart.[4,8] At the same time, an increase in vascular resistance may lead to a temporary rise in blood pressure. Studies in healthy individuals have reported a moderate increase in systolic and diastolic blood pressure during or immediately after exposure to cold, although this response was usually transient.[4,5,8]

These changes are closely linked to the activation of the autonomic nervous system, particularly its sympathetic branch.[5,6] Stimulation of cold receptors leads to increased sympathetic activity and enhanced release of noradrenaline, which further intensifies blood vessel constriction.[5,6,14] It is worth noting, however, that the cardiac response is not always identical in all subjects. Heart rate and selected autonomic parameters may vary depending on the time of measurement, the protocol used, and the characteristics of the study population.[5,6,10]

A key feature of the haemodynamic response during cryotherapy is its transient nature.[1,2,8] Upon leaving the cryogenic chamber, peripheral vasoconstriction gradually subsides and blood flow is redistributed to superficial tissues. This phase is sometimes interpreted as one of the mechanisms that may be relevant to post-exercise recovery; however, the available data do not yet allow for a clear determination of its actual practical significance.[11–13]

### 4.2. Possible adaptive processes with regular use of cryotherapy

In the case of repeated exposure to cold, the body may gradually adapt to this stimulus by developing adaptive mechanisms.[5,6] This phenomenon is well known in environmental physiology and concerns both thermoregulatory responses and the functioning of the cardiovascular system.[5,6] In practice, this means that the body's response to a subsequent stimulus may be less pronounced than during the first exposure.

One possible manifestation of such adaptation is a reduction in the severity of the acute haemodynamic response during subsequent sessions.[5,6,10] Some studies have observed that individuals who regularly undergo cryotherapy exhibit less pronounced autonomic and haemodynamic responses than during their first exposures.[5,6,10] It should be emphasised, however, that data in this area are limited, and the results of individual studies are not always fully comparable.[5,6,10]

Adaptation may also concern the autonomic regulation of cardiac function.[5,6,10] Studies following a series of treatments have sometimes described a reduced sympathetic response and a faster return to autonomic balance after exposure.[5,6,10] These phenomena are sometimes interpreted as a possible manifestation of habituation to the cold stimulus and may potentially be significant for regenerative processes.[5,6,10] However, they should not be presented as an effect unequivocally confirmed in all populations.

Another possible adaptive mechanism is more efficient regulation of blood flow in response to temperature changes.[5,6,8] Regular exposure to cold may promote a faster restoration of haemodynamic balance after the stimulus ends, but the significance of these changes for cardiovascular health and sporting practice remains a subject of ongoing research.[5,6,8] For this reason, when describing chronic effects, it is more appropriate to speak of possible adaptive processes rather than of permanent, well-documented cardiovascular benefits.

### 4.3. The significance of the observed changes for the functioning of the cardiovascular system

An analysis of the haemodynamic responses induced by systemic cryotherapy provides a better understanding of how this method affects the cardiovascular system. Sudden exposure to cold acts as a distinct stimulus to the circulatory system, as it leads to an increase in vascular resistance and changes in cardiac function.[1,4,5,8] At the same time, due to the short duration of exposure and the body's relatively rapid return to equilibrium, these reactions are usually well tolerated in healthy individuals and are transient in nature.[1,4,5,8]

In the context of sport and post-exercise recovery, it is particularly important that changes in blood flow may influence the processes occurring in skeletal muscles following intense exercise. Vasoconstriction occurring during exposure to cold may temporarily restrict perfusion of peripheral tissues, whilst in the post-exposure period there is a gradual redistribution of blood flow.[11–13] This pattern of changes is sometimes interpreted as one of the possible mechanisms supporting recovery; however, its actual practical significance remains debatable, as does the effect of cryotherapy on objective indicators of the return of exercise capacity.[11–13,17]

From a clinical perspective, it is also important to determine the safety of cryotherapy in individuals with cardiovascular diseases. Most available studies indicate that short-term exposure to cold is well tolerated by healthy individuals. However, in patients with hypertension, coronary artery disease or cardiac arrhythmias, caution and appropriate medical assessment are necessary, as an increase in vascular resistance and transient haemodynamic changes may have greater clinical significance in these groups.[5,17,18]

In summary, systemic cryotherapy induces marked but usually short-lived changes in cardiovascular function. These reactions form part of the body's natural adaptive response to thermal stress and may be significant for both regenerative processes and autonomic regulation.[5,6,8] However, their interpretation requires consideration of individual differences among study participants and the specific characteristics of the cryotherapy protocols used.[5,6,10]

**Table 1. Acute and chronic effects of systemic cryotherapy on the cardiovascular system**

| Type of effect | Observed physiological changes | Possible mechanisms | Functional significance |
|---|---|---|---|
| **Acute vascular responses** | Vasoconstriction within the skin and peripheral tissues | Activation of cold receptors and stimulation of the sympathetic nervous system | Reduction in heat loss and redistribution of blood to central organs |
| **Blood pressure responses** | Transient increase in blood pressure and peripheral resistance | Vasoconstriction and increased release of catecholamines | Short-term increase in cardiovascular workload |
| **Changes in heart rate** | Slight fluctuations in heart rate during exposure | Interaction between sympathetic and parasympathetic activity | Regulation of blood flow in response to a cold stimulus |
| **Reactive vasodilation following exposure** | Vasodilation upon leaving the cryogenic chamber | Restoration of thermal equilibrium and local regulatory mechanisms | Increased blood flow in peripheral tissues |
| Potential adaptations with regular use | Stabilisation of haemodynamic responses and reduced intensity of the cold response | Autonomic and vascular adaptation | Improved tolerance to environmental stimuli |
| Possible changes in autonomic regulation | Increased parasympathetic activity in the post-exposure period | Modulation of autonomic balance | Potential support for regenerative processes |

## 5. Autonomic control of cardiac function under conditions of cold exposure

The autonomic nervous system plays a key role in regulating cardiac function and maintaining the body's haemodynamic balance under changing environmental conditions. In the event of sudden exposure to very low temperatures, as occurs during systemic cryotherapy, there is a rapid activation of the autonomic mechanisms responsible for the body's adaptation to the stressor. However, this response is not entirely monophasic. Initially, activation of sympathetic mechanisms is observed, whilst in the post-exposure period, some studies have also described an increase in indicators associated with parasympathetic activity.[5,6,10]

From a physiological point of view, cold is one of the environmental stimuli that trigger a complex neuroregulatory response. Stimulation of thermal receptors in the skin leads to the

transmission of nerve impulses to regulatory centres located in the brainstem and hypothalamus.[3,7] It is there that information regarding the body's condition is integrated, and the appropriate autonomic responses are subsequently triggered. Consequently, changes occur in the activity of the sympathetic and parasympathetic nervous systems, which affect both heart rate and blood vessel tone, as well as overall circulatory regulation.[5,6,10]

In studies on systemic cryotherapy, particular attention is paid to the effect of cold exposure on autonomic balance. This is significant not only for the functioning of the cardiovascular system, but also for the regenerative processes occurring after physical exertion.[5,6,10] For this reason, the analysis of autonomic control of cardiac function constitutes an important element of research into the physiological effects of cryostimulation.

### 5.1. The role of the sympathetic and parasympathetic nervous systems in the response to cryostimulation

During exposure to extreme cold, the first stage of the autonomic response is usually the activation of the sympathetic branch of the autonomic nervous system.[5,6,14] This results from the stimulation of cold receptors located in the skin, which transmit information about a sudden drop in temperature to regulatory centres in the central nervous system. Consequently, there is an increased release of noradrenaline and a rise in the concentration of catecholamines in the bloodstream.[5,6,14]

Activation of the sympathetic nervous system directly affects the functioning of the circulatory system. One of its primary effects is an increase in blood vessel tone, which limits heat loss from the body.[5,6,8] At the same time, changes in heart rate and haemodynamic load may occur. It is worth noting, however, that the heart's response is not always identical across all studies and may depend on the time of measurement, exposure temperature and the characteristics of the study group.[5,6,10]

Over time, particularly after the end of cold exposure, the nature of the autonomic response may change. Some studies have shown that upon exiting the cryogenic chamber, there is an increase in parasympathetic activity, which is reflected in selected HRV indices.[5,6,10] This response is sometimes interpreted as part of the restoration of physiological balance following a short-term stressor.

This transition from an acute sympathetic response to increased parasympathetic activity is often cited as one of the potential mechanisms explaining the possible effect of cryotherapy on recovery.[5,6,10] However, overly categorical conclusions should be avoided, as not all studies demonstrate the same effect, and its practical significance remains a subject of ongoing research.[5,6,10]

### 5.2. Analysis of heart rate variability as a tool for assessing autonomic regulation

One of the most commonly used tools for assessing autonomic regulation is heart rate variability analysis, abbreviated as HRV.[5,6] This method is based on the analysis of slight variations in the intervals between heartbeats, which reflect the influence of the autonomic nervous system on the functioning of the sinus node.

HRV is considered a useful indicator of the balance between sympathetic and parasympathetic activity, but its interpretation requires caution.[5,6,10] Higher values of selected HRV indices

are often associated with greater parasympathetic activity and better adaptive capacity of the body, whereas reduced variability may accompany a predominance of sympathetic activity or greater physiological stress.[5,6,10] However, this does not mean that a single HRV parameter always allows for an unambiguous determination of the state of autonomic regulation.

In studies on systemic cryotherapy, HRV analysis is frequently used to assess the impact of cold exposure on the autonomic control of cardiac function.[5,6,10] In some studies, an increase in HRV indices was observed after the procedure, suggesting increased parasympathetic activity and a potential regenerative effect.[5,6,10] However, these results should be interpreted within the context of the entire study protocol, rather than as standalone evidence of the efficacy of cryotherapy.

This is because HRV values are influenced by many factors, including fitness level, sleep quality, psychological stress, hydration, time of day, and the conditions of the measurement itself.[5,19] For this reason, comparing the results of different studies can be difficult, particularly when the measurement protocols used differ significantly from one another.[5,6,10]

### 5.3. Long-term changes in autonomic balance resulting from repeated exposure

Repeated exposure to cold can lead to a gradual adaptation of the autonomic nervous system.[5,6] In the physiological literature, this phenomenon is referred to as habituation or autonomic adaptation and refers to a reduction in the body's response to a repeated environmental stimulus.[5,6]

In the case of systemic cryotherapy, this adaptation may manifest itself, amongst other things, as a reduced intensity of the catecholamine response and a weaker autonomic reaction during subsequent exposures.[5,6,10] Studies have observed that, following a series of sessions, the HRV and catecholamine responses may be less pronounced than after the first treatment, suggesting the development of habituation.[5,6,10]

It should be noted, however, that data on the long-term effects of cryotherapy on autonomic regulation remain limited.[5,6,10] Many studies involve small groups of participants and short observation periods, which makes it difficult to draw definitive conclusions regarding the durability of the observed changes.[5,6,10] Furthermore, the effect of cryotherapy on the autonomic nervous system may depend on numerous individual factors, such as fitness level, age or general health.[5,6,10]

Despite these limitations, short-term exposure to cold appears to be an interesting stimulus for modulating the functioning of the autonomic nervous system.[5,6,10] These mechanisms may be significant not only for the regulation of cardiac function, but also for the regenerative processes occurring after physical exercise.[5,6,10] For this reason, further research into the effects of systemic cryotherapy on the autonomic control of cardiac function remains an important area of development in modern exercise physiology and sports medicine.

## 6. Cryotherapy in the context of post-exercise recovery

Post-exercise recovery is one of the key elements of modern sports training. High training loads and frequent competition require methods that support the restoration of physiological balance following intense exercise. [5,11,13,19] In this context, there is growing interest in recovery strategies based on controlled exposure to environmental stimuli, including extremely low

temperatures. Systemic cryotherapy is one of the methods that has gained particular popularity in the sporting community in recent years.[5,11,13,20]

From a physiological point of view, physical exertion leads to a series of changes in the body, including microdamage to muscle fibres, increased inflammatory processes, metabolic imbalances and fatigue of the central nervous system.[11,12,19] The recovery process involves the gradual restoration of homeostasis through the repair of damaged cellular structures, the replenishment of energy reserves, and the normalisation of regulatory systems. It is precisely in this context that methods are sought which could support or accelerate these processes.

Exposure to cold can affect the body in several ways. The most commonly cited effects include changes in blood flow through muscle tissue, possible modulation of inflammatory processes, effects on the activity of the autonomic nervous system, and an improvement in athletes' subjective well-being.[5,11-13] It must be emphasised, however, that the effectiveness of cryotherapy as a tool to aid post-exercise recovery remains a subject of debate, and the results of available studies are not always conclusive.[11-13,17]

### 6.1. Perceived recovery and perceived muscle fatigue

One of the most frequently studied effects of cryotherapy in sport is its impact on the subjective sensation of fatigue and muscle soreness that occurs following intense physical exertion. Delayed onset muscle soreness (DOMS) is a natural consequence of microdamage to muscle fibres and the accompanying inflammatory processes.[11,12] It usually appears within 24–72 hours after exercise and may limit the ability to perform subsequent training sessions.

In the sporting community, there is a widespread belief that exposure to cold can reduce the severity of this phenomenon.[11,13,22] Some studies do indeed indicate a beneficial effect of cryotherapy on the subjective perception of pain and fatigue; however, this effect is not always fully reflected in objective indicators of recovery.[10,11,13,17,22]

In many studies, athletes undergoing cryotherapy after intense exercise reported an improvement in well-being and reduced feelings of fatigue.[13,17] This effect may result from both the physiological action and the perceptual impact of the treatment itself. Cryotherapy is a sensory-intense experience, which may influence the perception of fatigue and readiness for further exercise.[13,17]

For this reason, an improvement in subjective well-being following the treatment should not automatically be equated with more complete physiological recovery.[10,11,22] Rather, it is one of the key components of the response to cryotherapy, which should be interpreted in conjunction with other indicators.

### 6.2. Physiological parameters associated with the recovery process

In addition to athletes' subjective experiences, researchers are also analysing the effect of cryotherapy on various physiological indicators related to recovery. The most commonly assessed include markers of muscle damage, such as creatine kinase activity, levels of inflammatory markers, and performance parameters, including the ability to generate muscle strength following exercise.[10,11,17]

In some studies, a slight reduction in inflammatory marker levels was observed following cryotherapy, which may suggest a possible effect of cold on the processes associated with muscle microdamage.[6,10,15,16] However, the results regarding the effect of cryotherapy on the rate of recovery of exercise capacity are less clear-cut. Some experiments showed a slight improvement in performance parameters, whilst others found no significant differences between groups using cryotherapy and control groups.[10,11,17,22]

These differences may stem from the considerable variability in the research protocols used.[5,10,11] Among other factors, individual studies differ in terms of exposure temperature, treatment duration, number of sessions, and the timing of their application relative to physical exertion. Individual characteristics of the subjects, such as fitness level, the nature of the sport practised, or the body's degree of adaptation to physiological stress, may also be significant.[5,10,17]

It is also worth noting that the effect of cryotherapy on recovery may be indirectly linked to its impact on the autonomic nervous system. If exposure does indeed lead to an increase in parasympathetic activity, this may aid in restoring physiological balance after exercise.[5,6,10] At the current stage of research, however, this should be regarded as a possible mechanism rather than one that has been unequivocally confirmed.[5,6,10]

### 6.3. A possible link between exposure to cold and sleep quality

One aspect of recovery that has gained particular significance in research into elite sport in recent years is sleep quality. Sleep plays a fundamental role in the body's repair processes, influencing, amongst other things, tissue regeneration, hormonal regulation and the functioning of the nervous system.[19] For this reason, methods are being sought that could help improve sleep quality in athletes undergoing intense training loads.

Some studies suggest that whole-body cryotherapy may indirectly influence sleep parameters by modulating the autonomic nervous system and altering the body's thermal response.[17,20,21] Improvements in certain sleep parameters and increased parasympathetic activity have been reported, particularly when exposure was administered at a specific time in the evening.[20,21] However, these are preliminary results that require cautious interpretation.

For this reason, the relationship between cryotherapy and sleep quality should be regarded as a promising but still not fully understood area of research.[20,21] Further analyses are needed, encompassing both objective sleep measurements and long-term observation of athletes using cryotherapy as part of their recovery strategies.[20,21]

In summary, whole-body cryotherapy may influence various aspects of the post-exercise recovery process, encompassing both subjective feelings of fatigue and selected physiological parameters.[10,11,13,17,22] At the same time, the available data indicate that the effectiveness of this method depends on many factors, including the method of application and individual physiological characteristics.[5,10,17] For this reason, cryotherapy should be regarded as one element of a comprehensive recovery strategy rather than as a standalone solution with predictable effects in all athletes.[11,13,17,19]

**Table 2. Potential effects of cryotherapy on post-exercise recovery**

| Area of effect | Observed effects | Possible physiological mechanisms | Significance for athletes |
|---|---|---|---|
| **Delayed onset muscle soreness (DOMS)** | Reduction in the subjective sensation of muscle pain | Restriction of blood flow and modulation of inflammatory processes | Faster return to training |
| **Inflammatory processes** | Potential reduction in inflammatory markers | Inhibition of inflammatory mediators and changes in microcirculation | Support for tissue regeneration |
| **Perceived fatigue** | Improvement in subjective well-being and perceived level of recovery | Effect on the autonomic nervous system and perception of exertion | Better tolerance of subsequent training sessions |
| **Autonomic regulation** | Increased parasympathetic activity following exposure | Changes in autonomic balance | Supporting the body's regenerative processes |
| **Sleep and night-time recovery** | Possible improvement in sleep quality | Modulation of body temperature and autonomic activity | Improved recovery of the central nervous system |
| **Performance parameters** | Ambiguous research findings | Complex interactions between inflammatory processes and training adaptation | Requires further research |

## 7. Safety considerations and limitations of cryotherapy

Despite the growing popularity of systemic cryotherapy in sport and regenerative medicine, its use requires caution. Exposure to extremely low temperatures is a powerful physiological stimulus that triggers a series of adaptive responses, particularly within the cardiovascular and autonomic nervous systems.[5,17,18,21] In healthy individuals, these reactions are usually short-lived and well tolerated; however, this does not mean that the method is entirely risk-free. In certain clinical situations, it may place a significant strain on the body, especially if the procedure is performed without appropriate qualifications and supervision.[5,17,18]

For this reason, in clinical and sports practice, recognising situations in which cryotherapy may be associated with an increased risk is just as important as assessing the potential benefits.

Proper qualification for the procedure, preparation of the person undergoing exposure, and adherence to safety procedures are of key importance here.[17,18,21] Current expert reviews also emphasise the need for a cautious approach to lists of contraindications, as some of these are based more on clinical consensus than on very strong experimental data. [17,18]

### 7.1. Adverse reactions associated with exposure to extreme cold

Exposure to very low temperatures can trigger various physical reactions, which in most cases are temporary and do not lead to long-term health consequences.[17,18] The most commonly observed symptoms include a sensation of intense cold, temporary reddening of the skin, increased muscle tension and rapid breathing in the initial moments of exposure to the cold.[3,17,18] These symptoms result from the body's natural response to a sudden change in ambient temperature.

In some people, however, the reaction may be more pronounced. Increased blood vessel tension may lead to a temporary rise in blood pressure, and stimulation of the sympathetic nervous system may be associated with a sensation of heart palpitations, anxiety or increased psychophysical arousal.[5,8,17,18] In people who are more sensitive to the cold, dizziness or marked discomfort associated with a sudden change in temperature may also occur.[17,18] Although serious adverse effects are rare, isolated vascular and neurological complications have also been described in the literature; therefore, this procedure should not be regarded as entirely physiologically neutral.[17,18]

It is also worth mentioning the risk of local skin reactions. A correctly performed treatment is too brief to typically lead to serious tissue damage; however, if the procedure is performed incorrectly, with insufficient body protection or the presence of moisture on the skin, irritation may occur, and in extreme cases, frostbite may also result.[2,17,18] Therefore, the use of appropriate protective clothing, such as gloves, socks and ear protection, is a standard part of the cryotherapy procedure.[2,17,18]

### 7.2. Clinical situations requiring particular caution

There is a group of medical conditions and clinical states in which exposure to extreme cold may be associated with an increased risk. This applies primarily to cardiovascular diseases, in which haemodynamic responses triggered by cold can lead to excessive strain on the circulatory system.[5,17,18] Current guidelines and reviews highlight, among others, uncontrolled hypertension, unstable coronary artery disease and severe cardiac arrhythmias as being of particular significance.[5,17,18]

Particular caution should also be exercised in individuals with peripheral vascular disease. In such cases, severe vasoconstriction induced by cold may temporarily impair blood flow in the limbs.[17,18] Similar precautions apply to people with Raynaud's syndrome, in whom an excessive vascular response to cold may lead to painful episodes of ischaemia in the fingers and toes.[17,18] Important contraindications or conditions requiring individual assessment also include cryoglobulinaemia, hypersensitivity to cold, paroxysmal cold haemoglobinuria, and significant sensory disturbances.[17,18]

In practice, this means that the decision to use cryotherapy should not be based solely on the general opinion regarding its effectiveness, but on an assessment of the specific patient or athlete.[17,18,21] In some cases, caution and modification of the procedure are sufficient; in

others, it may be more appropriate to refrain from treatment altogether. This approach is more in line with the current state of knowledge than the creation of overly broad, automatic lists of contraindications.[17,18,21]

### 7.3. The importance of appropriate qualifications and supervision during procedures

The safety of systemic cryotherapy largely depends on the appropriate selection of patients and adherence to the relevant procedures.[17,18] Before commencing a course of treatment, it is recommended that a medical history be taken to identify any contraindications. In selected cases, it may also be appropriate to carry out a basic cardiovascular assessment, particularly where the medical history reveals chronic conditions or symptoms suggesting reduced tolerance to cold.[17,18]

Equally important is the organisation of the treatment itself. Exposure to extreme cold should take place under the supervision of appropriately trained staff who monitor the course of the procedure and respond should any worrying symptoms arise.[2,5,17] The duration of a single session is usually strictly defined and typically ranges from two to three minutes, which reduces the risk of excessive cooling. In practice, therefore, safety depends not only on the method itself, but also on the quality of its execution.[2,5,17]

It is also important to introduce the cold stimulus cautiously, particularly in people undergoing cryotherapy for the first time.[17,18] In practice, this means not so much arbitrarily extending exposure in subsequent sessions, but rather gradually acclimatising to the procedure and strictly adhering to the established treatment parameters. This approach can improve cold tolerance and reduce the risk of adverse reactions.[17,18]

In summary, systemic cryotherapy can be used safely, provided that the principles of patient selection, supervision and safety during the procedure are observed.[17,18,21] Understanding the limitations of this method and identifying groups requiring particular caution are key elements of the responsible use of cryostimulation in both medicine and sport.[17,18,21]

## 8. Limitations of the available studies and gaps in knowledge

Despite the growing number of publications on systemic cryotherapy, the current state of knowledge remains inconclusive.[5,10,13,22] Many studies point to the potential benefits of exposure to extreme cold, but at the same time highlight significant methodological limitations in the available research.[5,10,22] These relate to both the size of the study groups and differences in the protocols used, which makes it difficult to directly compare the results.[5,10,22]

One of the most frequently cited issues is the high variability in the conditions under which cryotherapy is administered.[5,10,13,17] Individual studies differ in terms of the temperature in cryogenic chambers, the duration of a single session, the number of treatments, and the intervals between successive exposures.[5,10,13] Furthermore, they involve very different participant populations — ranging from physically inactive individuals, through amateur athletes, to elite competitors. These differences can significantly influence how the body responds to the cold stimulus, thereby complicating the interpretation of results.[5,10,17]

Another limitation is that many studies focus on short-term effects.[5,10,22] Analyses covering a period of several days or weeks allow for the assessment of the body's immediate reactions to cold exposure, but say little about the long-term consequences of regular use of this method.[5,6,10] In particular, there is a lack of studies involving multi-month observation of athletes or patients using cryotherapy systematically.[5,6,10]

It is also worth noting the limited number of randomised trials with appropriate control groups.[10,13,22] In many cases, the results are based on the analysis of small sample sizes or on observational studies which, although they provide valuable information, do not always allow for a clear determination of the cause-and-effect relationship between exposure to cold and the observed physiological changes.[10,13,22] An additional problem is the difficulty in blinding participants, which may particularly affect subjective outcomes such as well-being, pain or perceived recovery.[10,13,22]

For this reason, further research into systemic cryotherapy should focus on greater standardisation of experimental protocols and on extending analyses to include the long-term effects of this method.[5,10] A particularly interesting avenue appears to be the combination of classical physiological measurements with the analysis of behavioural and psychological factors that may influence the subjective perception of recovery and general well-being following treatment.[5,10]

## 9. Directions for further research

In recent years, whole-body cryotherapy has become a standard feature of many training facilities and rehabilitation centres.[5,13,17,20] In elite sport, it is often used as part of a broader recovery strategy, which also includes proper nutrition, relaxation techniques and the management of training loads.[11,13,19,20] From the perspective of coaches and sports physiologists, its potential impact on recovery processes and on athletes' ability to maintain high training intensity in the following days remains of particular interest.[13,17,20]

In clinical practice, cryotherapy is primarily used in rehabilitation and in the treatment of certain musculoskeletal conditions.[16-18] In such situations, exposure to cold may be associated with reduced pain, reduced swelling and improved function, but the efficacy of these effects still requires further confirmation in well-designed studies.[16-18] For this reason, future work should focus more on specific clinical indications rather than on a general description of the 'beneficial effects' of cryotherapy.[10,16,17]

An important area for further research also remains the determination of optimal treatment parameters, such as temperature, duration of exposure, time of day and frequency of application.[5,10,20,21] This may be of particular importance in the context of sports recovery and sleep, as initial studies suggest that the timing of the treatment may influence its physiological effect.[20,21]

From the perspective of sport and regenerative medicine, it is also important to take into account individual differences among those using cryotherapy.[5,6,10] The body's response to cold may depend on fitness level, age, health status and previous experience with exposure to low temperatures.[5,6,10] Therefore, future research should focus more on identifying the groups that are likely to benefit most from this method.[5,6,10]

## 10. Conclusions

Systemic cryotherapy is an interesting method of influencing the body through brief exposure to extremely low temperatures. Available data indicate that exposure to cold triggers a series of physiological responses, including changes in blood vessel tone, alterations in cardiac function, and the activation of mechanisms for the autonomic regulation of circulation. These reactions are adaptive in nature and serve primarily to maintain homeostasis under conditions of a strong environmental stimulus.

In the context of post-exercise recovery, cryotherapy may influence the subjective perception of fatigue, muscle soreness, and certain physiological parameters associated with the body's recovery process following intense exercise. At the same time, research findings regarding the efficacy of this method remain inconclusive, particularly with regard to objective indicators of recovery and performance.

The issue of the safety of cryotherapy remains a key factor in interpreting the available data. Although short-term exposure to cold is generally well tolerated in healthy individuals, particular caution and appropriate medical supervision are required in certain clinical situations.

In summary, systemic cryotherapy may constitute a valuable component of recovery and rehabilitation strategies, but its use should be based on a conscious consideration of both the potential benefits and the limitations arising from the current state of knowledge. Further research into the physiological consequences of cold exposure may help to better determine in which situations this method actually offers the greatest practical value.

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The authors declare that they have no relevant financial or non-financial interests to disclose.

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Conceptualization: W.S.
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Validation: W.S., S.K., A.Pl.
Formal analysis: W.S.
Investigation: W.S., S.K., A.Pl., A.Py., A.Po., K.B.
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