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REVIEW

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The untapped potential of cold water therapy as part of a lifestyle intervention for promoting healthy aging

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Abstract Healthy aging is a crucial goal in aging societies of the western world, with various lifestyle strategies being employed to achieve it. Among these strategies, hydrotherapy stands out for its potential to promote cardiovascular and mental health. Cold water therapy, a hydrotherapy technique, has emerged as a lifestyle strategy with the potential capacity to evoke a wide array of health benefits. This review aims to synthesize the extensive body of research surrounding cold water therapy and its beneficial effects on various health systems as well as the underlying biological mechanisms driving these benefits. We conducted a search for interventional and observational cohort studies from MEDLINE and EMBASE up to July 2024. Deliberate exposure of the body to cold water results in distinct physiological responses that may be linked to several health benefits. Evidence, primarily from small interventional studies, suggests that cold water therapy positively impacts cardiometabolic risk factors, stimulates brown adipose tissue and promotes energy expenditure—potentially reducing the risk of cardiometabolic diseases. It also triggers the release of stress hormones, catecholamines and endorphins, enhancing alertness and elevating mood, which may alleviate mental health conditions. Cold water therapy also reduces inflammation, boosts the immune system, promotes sleep and enhances recovery following exercise. The optimal duration and temperature needed to derive maximal benefits is uncertain but current evidence suggests that short-term exposure and lower temperatures may be more beneficial. Overall, cold water therapy presents a potential lifestyle strategy to enhancing physical and mental well-being, promoting healthy aging and extending the healthspan, but definitive interventional evidence is warranted.

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Introduction

Hydrotherapy, a naturopathic therapeutic practice rooted in ancient civilizations including Egypt and China, has long been recognized for its potential to promote health and well-being [1, 2]. This multifaceted approach involves the external or internal use of water in various forms and temperatures to elicit physiological responses that can positively impact the body. The diverse range of hydrotherapy techniques, each possessing distinct characteristics and applications, has attracted significant attention from researchers, clinicians, naturopathic physicians and individuals seeking to harness its benefits. Hydrotherapy encompasses a spectrum of interventions, including compresses, immersion baths and steam baths, all of which leverage water's dynamic properties to maintain health and prevent and treat diseases. Among these techniques, cold water therapy has emerged as a lifestyle strategy with the potential capacity to evoke a wide array of health benefits.

Cold water therapy involves the deliberate exposure of the body to cold water, either partially or completely, resulting in distinct physiological responses that have been linked to several health benefits. The temperature range for cold water therapy can vary depending on the specific technique, intended purpose and individual tolerance. Generally, cold water therapy involves exposure to water temperatures that are colder than the body's normal temperature, which is around 37 °C (98.6°F).

The utilization of cold water therapy in promoting health and well-being can be traced back to historical practices, where cold water baths, plunge pools, cold water swims and cold water immersion (CWI) were embraced by cultures around the world. The first claims for the health benefits of cold water therapy date as far back as 3500 BC; Edwin Smith Papyrus made numerous references to the therapeutic purposes of cold water [3]. Hippocrates in 400 BC documented the use of cold water for analgesic benefits and medicinal purposes and for relieving fatigue [4, 5]. It was later reported that Thomas Jefferson used a cold foot bath every morning for six decades for its health benefits [6]. Over time, these traditional practices have gained renewed interest in contemporary settings, fuelled by mounting scientific evidence that underscores their potential to enhance overall health.

Vincent Priessnitz (1799–1851), a pioneer in the field of hydrotherapy, made significant contributions to the understanding and application of cold water treatments in the early nineteenth century [7–10]. Born in 1799 in Gräfenberg, Austria (now part of the Czech Republic), Priessnitz developed his methods through personal experience and observation. He founded the first hydrotherapy clinic in Gräfenberg, where he implemented his innovative approaches to health and healing. Priessnitz's techniques involved the use of cold water compresses, head, eye and foot baths, hip baths and full baths, showers and cold-water wraps to stimulate the body's natural healing processes [10]. He has laid the groundwork for modern hydrotherapy practices by emphasizing the importance of the body's ability to heal itself through natural means. Priessnitz's clinic attracted patients from across Europe, gaining widespread recognition and establishing him as a central figure in the development of naturopathic medicine. His methods have had a lasting impact, influencing subsequent generations of practitioners and contributing to the broader acceptance and integration of hydrotherapy in contemporary medical and wellness practices. Balneotherapeutic institutes modeled after the "Graefenberg model" were established in numerous countries across Europe, including Hungary [11]. The hydrotherapeutic innovations emerging from Gräfenberg also had a significant impact on the Vienna Medical School [12]. Wilhelm Winternitz (1834–1917), who became a lecturer in hydrotherapy in 1864, is often regarded as the "father of scientific hydrotherapy." He provided hydrotherapy with a physiological foundation, thereby paving the way for its institutional use in psychiatric settings. As a medical student, Winternitz wrote his dissertation on Priessnitz's "Wasserkur", conducting research that included measuring the pulse rates of Priessnitz's patients and performing other physiological tests to evaluate the efficacy of water-cure treatments. His work significantly contributed to the scientific validation and acceptance of hydrotherapy. Simon Baruch, an admirer of Wilhelm Winternitz, was a key advocate for hydrotherapy in the USA [13]. Sebastian Kneipp (1821–1897), a nineteenth century Bavarian priest, played a significant role in the development and popularization of hydrotherapy, building on the earlier work of Priessnitz [14, 15]. Kneipp expanded on Priessnitz's methods, which primarily focused on cold water applications, by integrating them into a holistic approach that included aspects of diet, exercise and herbal remedies. Kneipp's treatments, often referred to as the "Kneipp Cure", emphasized the therapeutic use of cold water through various techniques such as cold baths, showers and wraps. His contributions were instrumental in demonstrating the efficacy of hydrotherapy for a wide range of ailments, from circulatory disorders to chronic pain. Kneipp's holistic methodology and practical applications significantly influenced naturopathic practices worldwide, and his legacy persists in modern hydrotherapy and wellness traditions [16].

Modern cold water hydrotherapy, often administered through techniques such as cold water drinking, cold application or compress, cold showers, CWI and cold water or winter swimming, continues to attract attention for its purported benefits across a spectrum of health domains. Table 1 provides a brief overview of the various cold water therapy strategies and their specific temperatures. From facilitating recovery from exercise-induced muscle damage, ameliorating mood disorders, preventing respiratory tract infections, to enhancing cardiovascular function and immune responses [17–21], the effects of cold water therapy span both physiological and psychological functions. Moreover, recent research suggests that these interventions might influence metabolic processes, inflammatory pathways and even neurobiological mechanisms. These multifaceted effects support key aspects of well-being important for healthy aging and extending the healthspan. Healthy aging refers to the process of developing and maintaining functional ability that enables well-being in older age. It encompasses physical, mental and social well-being, allowing individuals to live independently and participate in activities that bring them joy and fulfilment [22]. Key aspects of healthy aging include the prevention of chronic diseases, maintenance of physical and cognitive function and active engagement in life. Healthspan denotes the duration of an individual's life during which they experience optimal health and are free from the chronic illnesses and disabilities that commonly arise with aging [23]. Aging populations are a significant demographic trend in the Western world, characterized by increasing life expectancy and declining birth rates. This demographic shift presents numerous challenges, including a rise in age-related diseases, increased healthcare costs and a growing need for long-term care. As the proportion of older individuals continues to grow, societies face the pressing task of ensuring that these additional years are not only longer but also healthier and more fulfilling. Promoting healthy aging is crucial for both individuals and society. For individuals, it enhances quality of life, reduces the burden of disease and extends the period of independent living. For society, healthy aging can alleviate the strain on healthcare systems, decrease the economic burden associated with chronic diseases and foster a more active and productive older population.

There is a breadth of modern scientific literature exploring the impact of cold water therapy on health, but the evidence is scattered and at times inconsistent. Hence, synthesizing the existing evidence becomes essential. This review aims to distill the body of modern research surrounding cold water therapy and its effects on various health systems. Through a comprehensive assessment of the underlying biological

Table 1 Cold water therapies

Type	Temperature, °C	Description
Cold water drinking	Varies	Consumption of cold water
Cold water compresses	Varies	Applying cold wet cloths or bandages to specific body areas
Cold showers	10–20	Exposing the body to cold water for a brief period, usually during a regular shower routine
Cold water immersion	< 15	Submerging the body in cold water for a specified duration
Ice baths	0–15	Immersing the body in a container filled with cold water and ice
Cold water/winter swims	< 15	Immersing oneself in cold natural bodies of water, such as lakes, rivers or oceans

The exact temperatures can vary depending on personal preferences, location and specific equipment mechanisms driving these benefits and exploration of potential clinical implications, this review seeks to provide an understanding of the role of cold water therapy in promoting health and well-being. In light of the ever-growing interest in optimizing human health and the need for evidence-based guidance, this review seeks to uncover the intricacies of cold water therapy's potential contributions to promoting healthy aging and enhancing overall healthspan.

Types of cold water therapy

Cold water drinking

Cold water therapy is not limited to external exposure. Consuming cold water may have certain effects on the body, such as temporarily boosting metabolism, enhancing thermogenesis, assisting with weight loss, boosting low blood pressure and promoting hydration [24, 25].

Cold water compresses

Cold water compresses involve applying cold, wet clothes or bandages to specific body areas for a period to induce localized cooling. This technique is often used to reduce inflammation, swelling and pain in specific joints or muscles [26].

Cold showers

Cold showers entail exposing the body to cold water for a brief period, usually during a regular shower routine. The temperature of a cold shower can range anywhere from around 10 to 20 °C (50 to 68°F). This form of cold water therapy is relatively more accessible and can stimulate vasoconstriction, increase alertness and possibly activate the body's adaptive stress response.

Cold water immersion

Cold water immersion involves submerging the body in cold water, typically at temperatures below 15 °C (59°F), for a specified duration. This technique is often utilized for its potential to elicit physiological responses that promote recovery from exercise-induced muscle damage, reduce inflammation and enhance circulation.

Ice baths

Ice baths, also known as cold baths or cold plunges, involve immersing the body in a container filled with cold water and ice, creating a lower temperature environment. Ice baths usually entail water temperatures ranging from 0 to 15 °C (32 to 59°F), depending on the amount of ice added. Athletes and individuals seeking rapid muscle recovery often use ice baths to mitigate muscle soreness and inflammation after intense physical activity.

Cold water or winter swims

Cold water swims—also known as winter swims or ice swims—involve immersing oneself in cold natural bodies of water, such as lakes, rivers or oceans ranging from a few degrees above freezing to around 15 °C (59°F) or below. The International Winter Swimming Association classifies event site water into three temperature categories: cold water (5.1 to 9.0 °C); freezing water (2.1 to 5.0 °C); and ice water (−2.0 to 2.0 °C) [27]. Cold water swimmers often experience a rush of endorphins, enhanced circulation and a sense of invigoration. Regular cold water swims have been associated with potential cardiovascular benefits and increased resilience to cold exposure.

Methods

We conducted a search for randomized controlled trials (RCTs), non-RCTs, observational studies (including prospective cohort, nested case–control, case-cohort or retrospective cohort studies) and systematic reviews and meta-analyses of these study designs, from MEDLINE and EMBASE up to July 2024. Our search focused on the cardiovascular and other health benefits of cold water therapies, with a particular emphasis on systematic reviews and meta-analyses of these study designs, according to the hierarchy of evidence [28]. We focused particularly on longitudinal studies given that they address the issue of temporality; however, results of some cross-sectional studies as well as case reports were discussed where relevant. We also included narrative reviews conducted on the topic. We combined search terms or keywords related to cold water therapy ("cold water therapy", "cold water compress", "cold water immersion", "ice bath", "cold shower") and cardiovascular and other health outcomes ("cardiovascular risk factors", "cardiovascular disease", "heart failure", "hypertension", "blood pressure", "dementia", "diabetes", "musculoskeletal system", "depression", "anxiety", "pulmonary disease", "sleep", "lipids", "inflammation", "oxidative stress", "arterial stiffness", "arterial compliance" and "intima media thickness"). The evidence on the health benefits was restricted to studies conducted in human populations, reported in English, and in adults. However, data on the pathways underlying the beneficial effects of cold water therapies also utilized evidence from animal studies given that the subject area is still emerging.

Health benefits of cold water therapy

Cardiometabolic health and the endocrine system

Cold therapy has been shown to have some beneficial effects on cardiovascular and metabolic risk factors, which may translate to lowering the risk of adverse cardiometabolic outcomes such as cardiovascular disease (CVD) and type 2 diabetes (T2D). In a controlled study by Sramek and colleagues in which a group of young men were immersed in cold water at 14 °C for an hour, this increased basal metabolic rate by 350% and reduced heart rate, systolic blood pressure (SBP) and diastolic blood pressure (DBP) by 5%, 7% and 8%, respectively [29]. Diastolic blood pressure was significantly reduced in seven long-distance swimmers who swam in 10–14 °C water for 4 days [30]. Cold water exposure leads to an immediate increase in blood pressure levels due to the body's cold shock response, but blood pressure levels improve when practiced regularly especially in generally healthy people. A study evaluated the impact of cold water swimming on seasonal changes in lipid profile and other cardiovascular risk factors in 34 cold water swimmers aged 48–68 years and demonstrated reductions in triglycerides, apolipoprotein (Apo)B/ApoA-I ratios, body mass and homocysteine concentrations [31]. In 10-well cold-adapted winter swimmers and 16 non-adapted controls who were enrolled in an experiment to determine the effect of cold adaptation on cardiovascular risk factors, it was shown that cold-adapted winter swimmers have a higher capacity to deal with oxidative stress and there was a decrease in ApoB/ApoA-I ratio and levels of homocysteine [32]. Cold exposure was shown to improve peripheral glucose uptake and insulin sensitivity among 15 healthy men [33]. In a single-group repeated-measures study design in which the effect of cold hip baths on blood glucose levels was evaluated among eight patients with T2D, the results showed that a 20-min cold hip bath was effective at reducing blood glucose levels compared with a simple rest [34]. Repeated cold water swimming (twice weekly during the winter months) among 14 recreational female swimmers resulted in increased insulin sensitivity and decreased insulin and leptin concentrations [35]. Among 30 healthy men and women who underwent cold water swims at least twice a week for six consecutive months, females and lean subjects demonstrated increased insulin sensitivity as well as a reduction in insulin secretion and resistance [17]. In eight patients with T2D, 10 days of cold acclimation (14–15 °C) increased peripheral insulin sensitivity by ~43% [36]. Cold water therapy also affects the release of other hormones such as catecholamines, thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), beta-endorphins, dopamine and cortisol [19, 37–41]. The acute hormonal and metabolic effects of long-distance swimming in cold water were evaluated in 22 long-distance swimmers; following the competition, there was an increase in plasma catecholamines (epinephrine, norepinephrine), cortisol, thyroxine, free fatty acids and lactate, with a decrease in glucose and insulin levels [39]. There were increases in levels of ACTH, cortisol and norepinephrine among swimmers who participated in winter swimming three times a week at water temperatures of 0–3 °C for 12 weeks [37]. In a study which compared habitual and inexperienced winter swimmers, significantly higher concentrations of cortisol were observed in winter swimmers compared to inexperienced subjects [41]. In the controlled study by Sramek and colleagues, CWI increased dopamine concentrations by 250% [29].

Kidney disease and renal function

Cold water therapy has been shown to have a positive impact on various systems of the human body, but its impact on kidney disease and function is not fully understood because of limited research evidence. While some anecdotal reports suggest potential benefits like detoxification and increased circulation, there are concerns that cold water therapy might affect blood circulation and potentially impact kidney health. Indeed, CWI has been linked to acute renal failure (ARF); in a case report of a 27-year-old Japanese man who developed ARF associated with CWI, the clinical course was consistent with ARF attributable to acute tubular necrosis due to vasoconstriction and ischemia induced by cold exposure [42].

Cognitive function and neurodegenerative disease

Cold water therapy has garnered attention for its potential benefits on cognitive function and the prevention or mitigation of neurodegenerative diseases. The therapeutic application of cold water is believed to have a positive impact on brain health due to its ability to trigger various physiological responses. Importantly, exposure to cold water stimulates the production of the neurotransmitter, norepinephrine, that plays a key role in enhancing alertness, attention and mood. The release of norepinephrine is thought to improve cognitive performance by increasing brain activity and promoting neural plasticity [43–45]. However, studies of the effects of cold water therapy on cognitive function have produced varying results [46]. In a systematic review of 18 studies comprising eight studies investigating the effects of cold air exposure and 10 the effects of CWI on cognitive performance of healthy subjects, cold exposure was shown to induce an impairment in cognitive performance in 15 out of the 18 experimental settings [46]. In a study that sought to determine whether cold water consumption influenced cognitive response during high-intensity exercise in a hot environment, a short bout of high-intensity exercise improved cognitive function, but cold water consumption did not have an effect on cognitive function [47]. In a study that determined the effects of repeated CWI on cognitive performance and neurophysiological function in 12 healthy participants, cognitive performance was improved following the intervention [48]. Additionally, the stress response induced by cold water immersion can improve resilience to stress, which is beneficial for maintaining cognitive function under pressure.

Cancer

While there is no evidence to show that cold water therapy can be used to treat or prevent cancer, a number of studies have suggested that cold therapy can lower the incidence of chemotherapy-induced peripheral neuropathy (CIPN) arising from the use of paclitaxel [49–51], an agent commonly used for the chemotherapeutic treatment of gynaecological cancers. In a recent RCT of gynecological cancer patients who were receiving chemotherapy which included paclitaxel and allocated to control and cold-therapy groups, frozen gloves used as part of cold therapy was shown to significantly decrease the incidence of CIPN [52].

Infections and immunity

There is emerging evidence suggesting that cold water therapy may enhance resistance by improving the immune system, thus having the ability to prevent and/or reduce the severity of infections. Six weeks of repeated CWIs have been shown to activate the immune system of athletic young men to a slight extent, reflected by increases in the plasma concentrations of interleukin-6 (IL-6) and the amount of total T lymphocytes (CD3), T helper cells (CD4), T suppressor cells (CD8) and activated T and B lymphocytes (HLA-DR) [53]. In a study which compared habitual and inexperienced winter swimmers, significantly higher concentrations of plasma IL-6, leukocytes and monocytes were observed in winter swimmers compared to inexperienced subjects [41]. In 15 healthy subjects who participated in 150-m-long swimming race in cold water (6 °C), there was a significant increase in levels of leukocytes (neutrophil granulocytes, lymphocytes and monocytes) [54]. In another study in which 15 healthy men were subjected to whole-body cryostimulation (3 min/−130 °C) twice before and after the winter swimming season, increased levels of leukocytes and monocytes were reported after the winter swimming season [55]. Other studies have reported contrasting results. Versteeg and colleagues [56] investigate the effects of a 3-week repeated CWI intervention on leukocyte counts in 12 non-cold adapted men and observed no differences in leukocyte count between CWI and the control group. Jansky investigated the immune system's response of individuals who were initially immersed in cold water followed by repeated CWI three times a week over 6 weeks; their results showed no significant changes in levels of immunoglobulins (IgG, IgM, IgA) and C3, C4 components of the complement, as well as the total number of erythrocytes, leucocytes, granulocytes and neutrophils following CWI [53]. Though the increases in immune function markers may suggest improved immune function, they do not accurately reflect this state; furthermore, it is challenging to accurately measure in vivo immune function.

Respiratory tract infections (RTIs) are useful proxy measures of in vivo immune function; however, evidence on the relationship between cold water therapy and RTIs has been mostly inconsistent. In the first-ever study to assess the link between cold water therapy and respiratory diseases, Brenke surveyed 85 ice swimmers who regularly participated in cold water swims—40% of them stated that they experienced fewer, more mild and shorter duration infections of the upper respiratory after they started regular ice swimming and it was also observed that there was a significant reduction in consultations for respiratory illnesses [57]. Another study compared the incidence and severity of upper airway infections in cold water swimmers with those within their immediate social circle (non-swimmers, partners and pool swimmers) and found that cold water swimmers reported similar episodes of RTI compared to the other groups [20]. Following repeated cold water stimulations in 20 patients with chronic obstructive pulmonary disease, there was a decrease in the frequency of infections and quality of life was improved [58]. Kormanovski and colleagues [59] investigated the immune response as well as resistance to respiratory illness in open water swimmers during training and long-distance swims over 6 months; they reported a significant reduction in serum and salivary antibodies with no change in resistance to respiratory illnesses.

The inconsistencies in the evidence may reflect the variations in level of cold water acclimatization, temperature, duration of exposure to cold water therapy and individual physiological responses. It has been reported that short-term exposure to cold water therapy may improve the immune system, but repeated or excessive exposure without optimal recovery could lead to physiological stress which could impair immune function [4, 60]. Other possible contributing factors to the increased susceptibility to RTIs as a result of cold water exposure include increased vasoconstriction as a result of breathing in cold air [61].

Bone and musculoskeletal health

Cold water therapies have been widely used to treat inflammatory diseases of the joints, including rheumatoid arthritis (RA), but the body of scientific evidence regarding its effectiveness is quite limited. In an open-label, randomized, one-way crossover clinical proof-of-concept trial in which 24 patients with moderately active axial spondylarthritis were randomized to an add-on training program (involving breathing exercises, CWI and meditation) and a control arm, the intervention was shown to be safe and potentially modulated immune response [62]. The authors noted that future research should include a larger sample size to formally evaluate the clinical efficacy of the combined and/or individual components of the training program [62]. Among 82 winter swimmers and non-swimmers who completed questionnaires to assess their mood before and after 4 months of winter swimming, all swimmers with conditions such as rheumatism or fibromyalgia reported improved pain [18].

Skin conditions

Cold water therapies, such as cold showers or ice baths, may offer several benefits for skin health. Potential advantages include the temporary reduction in the appearance of pores and puffiness due to vasoconstriction of blood vessels in the skin, a decrease in inflammatory skin issues and healthier skin resulting from improved blood flow. While these benefits are biologically plausible, they are not yet supported by robust scientific evidence.

Mental and sleep health and general well-being

Cold water therapy has been shown to improve mental health disorders, sleep, quality of life and general well-being. Forty-nine winter swimmers and 33 non-swimmers completed questionnaires to assess their mood before and after 4 months of winter swimming; results showed that adaptation to cold water was associated with a significant decrease in tension and fatigue and an improvement in mood and memory [18]. Swimmers felt more vigorous, energetic, active and brisk than the controls [18]. Twenty-five Finnish winter swimmers and 11 controls were followed prospectively during the winter season to determine whether winter swimming was beneficial for mental well-being [63]. Results from self-reported questionnaires showed that winter swimmers had improved physical symptoms and mood states [63]. Given that cold water therapy activates the sympathetic nervous system (SNS) and causes increase in levels of beta-endorphin and noradrenaline, it has been suggested that cold water therapy could be used for the treatment of depression [64]. Five of 13 recruited patients with a diagnosis of depression participated regularly in twice-weekly group-based cold water swimming [65]. At the end of the study, their well-being and sleep scores had improved [65]. In a meta-analysis of nine studies, Bilgin and colleagues [66] showed that cooling therapies (cooling garment, cooling device, cooling room, precooling and cold water ingestion) had a beneficial effect on fatigue, physical activity and quality of life of patients with multiple sclerosis.

Cold water therapy and exercise

The synergy between cold water therapy and exercise is becoming well known for its potential to enhance performance, recovery and overall exercise-related benefits. The interplay between these two interventions unveils a relationship that spans pre-, during and post-exercise stages. Cold water therapy has been proposed as a preparatory strategy before exercise. This is rooted in the activation of the SNS that occurs in response to cold water exposure [19, 37]. The surge in norepinephrine release contributes to heightened alertness and increased heart rate, potentially priming the body for physical exertion. Moreover, cold water therapy might induce a mild stress response that fosters hormetic adaptations, which could translate to improved exercise resilience. Incorporating cold exposure during exercise raises interesting possibilities, particularly in endurance activities. Some athletes have explored the concept of "thermal loading", using ice vests or CWI to maintain core temperature during prolonged exertion [67]. By countering the rise in body temperature, these strategies aim to extend the duration of optimal performance. Several studies suggest that drinking cold water during exercise may improve performance and endurance [25, 68, 69]. Cold water therapy's role in post-exercise recovery is perhaps one of its most well-explored facets. Taking a cold plunge post-exercise is a common practice among many athletes. It has been reported that this practice reduces muscle pain and soreness after training sessions and competitions and promotes faster recovery. Cold water therapies have been investigated for their potential to attenuate exercise-induced muscle damage, inflammation and soreness. However, studies performed so far have been based on small sample sizes and/or their results have been inconsistent. Some studies have reported positive results, others have been inconclusive, whereas others have rather reported an increase in muscle soreness and pain following post-exercise cold water therapy [70–73]. Leeder and colleagues [74] compared competing professional athletes recovering with and without post-exercise CWI and assessed recovery markers of sprint performance, muscle function, muscle soreness and biochemical markers associated with damage (creatine kinase (CK)), inflammation (IL-6 and CRP) and oxidative stress (lipid hydroperoxides and activity of lipid-soluble antioxidants). The post-exercise CWI group showed improved recovery time of sprint speed 24 h post-exercise and an attenuated efflux of CK [74]. In a randomized, cross-over design that investigated the effect of CWI vs active recovery on the recovery of muscle function and physiological responses after high-intensity resistance exercise, CWI did not alter recovery of maximal strength or countermovement jump performance, but enhanced recovery of submaximal muscle function [75]. It also substantially reduced muscle temperature and muscle soreness and swelling compared with active recovery [75]. Similar studies have demonstrated that CWI following exercise offers greater recovery benefits such as reduction in muscle soreness and decreased muscle metabolic activity [76, 77]. In a systematic meta-analysis of 68 studies that evaluated the effect of CWI on the temporal recovery profile of physical performance, accounting for environmental conditions and prior exercise modality, CWI improved the recovery of endurance performance following exercise in warm but not temperate conditions. Furthermore, CWI improved strength recovery following endurance exercise performed at cool-to-temperate conditions and enhanced recovery of sprint performance following resistance exercise [78]. A Cochrane Database systematic review and meta-analysis of 17 small trials involving a total of 366 participants evaluated the effects of CWI in the management of muscle soreness after exercise [79]. The results showed that there was some evidence that CWI reduced delayed onset muscle soreness after exercise compared with passive interventions involving rest or no intervention [79]. In a RCT that sought to determine if ice-water immersion after eccentric quadriceps exercise minimizes the symptoms of delayed-onset muscle soreness, 40 untrained volunteers performed an eccentric loading protocol with their non-dominant leg and were randomised to three 1-min immersions in either ice water (5 ± 1 °C) or tepid water (24 °C) [70]. The results showed no significant differences between groups with regard to changes in most pain parameters, tenderness, isometric strength, swelling, hop-for-distance or serum CK over time. However, the intervention group demonstrated a greater increase in pain on sit-to-stand at 24 h [70]. In a study that compared the effects of CWI and active recovery on inflammatory and cellular stress responses in skeletal muscle from exercise-trained men 2, 24 and 48 h during recovery after acute resistance exercise, the responses did not differ significantly between CWI and active recovery [80]. In a pre-post interventional study that sought to determine the effect of CWI on physical performance (a 40-yard dash and a vertical jump) in 30 healthy volunteers, the results showed a decrease in physical performance immediately and 20 min after CWI [81]. Wilson and colleagues [82] assessed the effects of whole-body cryotherapy and CWI on markers of recovery in 31 endurance trained males who completed a marathon. The results showed that whole body cryotherapy had a negative impact on muscle function, perceptions of soreness and a number of blood parameters compared to CWI [82].

The inconsistencies in the evidence may reflect variations in the duration of exposure to cold water therapy, water temperature, cold water therapy protocol, type of exercise and individual level of experience to cold water therapy and physiological responses. A recent systematic review and meta-analysis sought to explore the impact of immersion time, water temperature, CWI protocol and type of exercise on the efficacy of CWI in the management of muscle soreness [83]. Analysis based on 44 studies showed that for immediate effects, CWI was superior to control strategies for relieving muscle soreness regardless of water temperature and exercise protocol, and for short and medium immersion times and endurance exercises. For delayed effects, CWI was superior to the control group in all subgroups except longer immersions time [83]. Total CWI was shown to be more effective when compared to ice massage on improving values of recovery from exercise-induced muscle damage among 60 participants [84]. A meta-analysis of 32 RCTs evaluated the effect of heat and cold therapy on the treatment of delayed onset muscle soreness and showed that application of cold therapy within 1 h after exercise could reduce pain [85]. In another systematic review and meta-analysis that investigated the effects of CWI on recovery of athletic performance, perceptual measures and CK following an acute bout of exercise in physically active populations, CWI improved muscular power, muscle soreness, CK and perceived recovery 24 h after exercise; furthermore, dose–response analyses suggested that shorter durations and lower temperatures may improve the efficacy of CWI if used after high-intensity exercise [86].

Postulated mechanisms underlying the potential beneficial effects of cold water therapy post-exercise include [70, 71, 87, 88] (i) the vasoconstriction induced by cold exposure may help reduce edema and facilitate the removal of products such as lactic acid, contributing to faster recovery; (ii) the potential analgesic effects of cold exposure can provide relief from exercise-induced pain; (iii) cold water exposure reduces swelling and tissue breakdown; and (iv) cold water exposure may slow down the physiological process due to a reduction in metabolism. The combination of cold water therapy and exercise present a potential dynamic interplay that spans preparation, performance and recovery. However, further evidence is needed.

Cold water therapy and sauna baths

Sauna bathing is a form of passive heat therapy, which is characterized by exposure to a high environmental temperature for a brief period. Though there are several types of passive heat therapy, the most widely used and researched are the Finnish saunas. They are characterized by high temperatures (ranging from 80 to 100 °C) and dry air with relative humidity varying from 10 to 20%. Sauna bathing is an activity that has been a tradition in Finland for thousands of years and has mainly been used for the purposes of pleasure and relaxation. It is now emerging as a lifestyle strategy linked to several health benefits, which include reduction in the risk of CVDs as well as non-CVDs [89–94]. Cold water therapy and sauna baths represent polar opposites on the temperature spectrum. Whereas cold water therapy typically involves exposure to cold water, sauna baths embrace the therapeutic power of heat in elevated temperatures. It is common practice for sauna bathers to combine short stays in the sauna room with rapid cooling-off periods which involve cold showers, jumping in ice cold water, cold water swimming or rolling on the snow [95]. The major aspect of combining cold water therapy and sauna baths is the potential for contrasting temperature exposures. This approach which involves moving between hot and cold environments in a deliberate sequence is known as contrast therapy. The rationale behind alternating between hot and cold exposures lies in the body's response to these temperature extremes. The heat from the sauna expands blood vessels, increasing blood flow to the skin. In contrast, the cold exposure causes blood vessels to constrict, diverting blood to the body's core. Advocates of contrast therapy believe it offers a range of potential health benefits. The alternating vasodilation and vasoconstriction can help improve circulation, ensuring that nutrients and oxygen are efficiently delivered to cells throughout the body, flushes out toxins and stimulates the immune system. It is also considered to have a potential impact on muscle recovery and pain relief [96]. The hemodynamic response to acute exposure to Finnish sauna followed by CWI was assessed in 37 male participants, and the results showed hemodynamic alterations in chronic heart failure patients with no provocation of an excessive increase in adrenergic activity or complex arrhythmias [97]. In a study that aimed to determine the effect of repeated hot thermal stress and CWI on the endocrine system of young adult men with moderate and high levels of physical activity, the results showed that the repeated exposures induced a significant decrease in cortisol concentrations but did not cause significant changes in other hormones [98]. Podstawski and colleagues [99] aimed to determine the effect of 16 min of thermal stress followed by 2 min of CWI on the physiological parameters of 55 sedentary men. The results showed that a 16-min sauna session followed by 2 min of CWI induced a significantly greater decrease in heart rate and blood pressure than a 16-min sauna session followed by 30 s in the shower and a 90-s resting period [99]. While contrast therapy may offer potential health benefits, the evidence is limited; hence, it is important to approach it with caution. This practice is generally safe for healthy persons but may be associated with adverse reactions such as cardiac arrhythmias [100] in patients with CVD. Alternating cold and heat exposure has been shown to have considerable strain on the heart [101] and also produces transient edema in the skin as a result of disturbance in the cutaneous circulation [102].

Potential pathways underlying the beneficial effects of cold water therapies

Endocrine and metabolic pathways

The potential mechanisms through which cold water therapies may exert their beneficial effects include several physiological responses, with endocrine and metabolic pathways emerging as key protagonists (Fig. 1). Cold water exposure triggers a cascade of reactions within the body, stimulating a release of several hormones and activation of metabolic processes that contribute to the observed health benefits. At the crossroads of these responses lies the activation of SNS, a cornerstone of the body's "fight or flight" response [19]. Cold water exposure stimulates the release of norepinephrine [19, 37], an SNS neurotransmitter, which orchestrates vasoconstriction and increased cardiovascular activity, including changes in the cardiac conduction system. This surge in norepinephrine (i) enhances blood circulation ensuring efficient oxygen and nutrient delivery to tissues while aiding in the removal of waste products; (ii) not only heightens alertness and focus but also has anti-inflammatory properties, which can aid in muscle recovery and pain reduction; and (iii) also elicits the release of beta-endorphins [64], endogenous opioids that impart analgesic and mood-enhancing effects, contributing to the invigorating sensations often associated with cold water exposure. Cold exposure also stimulates the release of dopamine [29, 33], a neurotransmitter that plays a crucial role in mood regulation, motivation and pleasure; it is often referred to

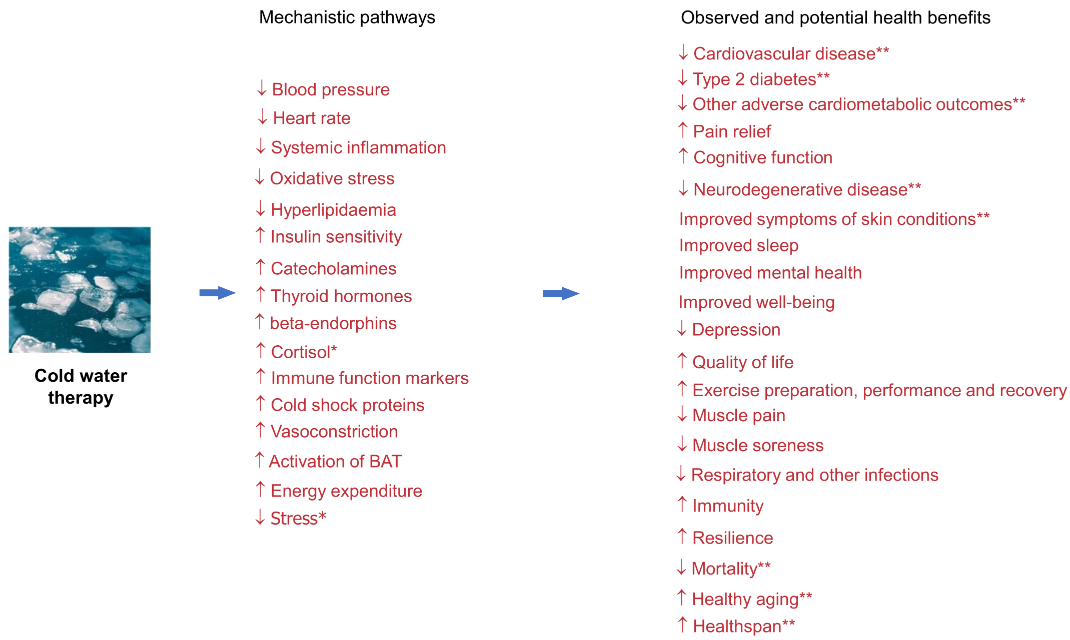

Fig. 1 Proposed mechanistic pathways underlying cold water therapies and observed and potential health benefits. This figure illustrates the potential mechanistic pathways underlying cold water therapies and its observed health benefits as well as potential benefits, which include preventing or delaying the onset of age-related diseases and mortality, promoting healthy aging and extending the healthspan. *While cold water therapy induces an acute increase in cortisol levels as part of the stress response, regular exposure can enhance stress resilience, reduce chronic stress and improve overall well-being through mechanisms such as endorphin release and activation of the parasympathetic nervous system. **These are potential benefits based on physiological adaptations produced by cold water therapies and observed effects in various studies. These benefits should not be interpreted as definitive outcomes without further conclusive evidence. BAT, brown adipose tissue

as the "feel-good" hormone. Further contributing to the physiological pathway is the modulation of the hypothalamic–pituitary–adrenal (HPA) axis, a central player in stress responses. Cold water immersion prompts the release of cortisol [37, 41], a stress hormone that initiates a controlled stress response. This transient elevation of cortisol levels is believed to foster resilience against subsequent stressors, a phenomenon known as hormesis [103]. The interplay of cortisol with other hormones, such as growth hormone and insulin-like growth factor 1 (IGF-1), underpins the regenerative and reparative effects associated with cold water therapy, supporting tissue repair and muscle growth. Cold water therapy has been shown to induce oxidative stress to a mild degree [104]; however, this repeated mild oxidative stress leads to adaptive changes which confer antioxidative protection [55, 104], enhancing the body's readiness to fight diseases. Cold water therapy may also confer its beneficial effects through its anti-inflammatory properties [41, 105–107]. Drinking ice water can decrease heart rate through temperature stimulus-mediated vagal enhancement [108]. Metabolically, cold water therapy imparts a dynamic influence on energy expenditure and substrate utilization. Cold exposure triggers thermoregulatory responses to conserve heat, which include cutaneous vasoconstriction and piloerection. This is then followed by activation of thermogenesis. Initially, skeletal muscle shivering takes place to generate heat (shivering thermogenesis), which is mediated by the somatic motor cortex in response to signals from cold receptors situated in the skin [109]. Shivering during cold exposure is more effective than physical activity in generating heat because the individual is less mobile and less heat is lost by convection [110]; shivering can generate heat at a rate of 10 to 15 kJ/min [111]. The peak shivering rate has been reported to be as high as fivefold the resting metabolic rate [112]. When cold exposure is sustained, non-shivering thermogenesis develops over the longer term [113]. This process is orchestrated by brown adipose tissue (BAT), which activates to generate heat through mitochondrial uncoupling, consuming energy stored as fats [114]. This contrasts with white adipose tissue, which stores energy. Activation of BAT leads to increased energy expenditure and reduction in levels of plasma triglyceride and cholesterol as well as improved glucose metabolism [33, 115], which can contribute to weight loss, protection from atherosclerosis and improved metabolic health [116]. Indeed, winter swimmers have been reported to have a relatively low prevalence of obesity and relatively high proportion of BAT, compared to other common adipose tissues [117]. Furthermore, the cold-induced activation of BAT has been linked to enhanced insulin sensitivity [116], which plays a pivotal role in glucose metabolism and can potentially mitigate the risk of T2D. Increased secretion of thyroid hormones following cold exposure also increase heat production and metabolism [118]. Amid these complex pathways, the role of adenosine monophosphate-activated protein kinase (AMPK) is notable. AMPK, often referred to as the "metabolic master switch", is activated in response to energy depletion, promoting cellular energy production and resilience [119]. Cold water therapy's potential to stimulate AMPK activation [120] aligns with its metabolic benefits, fostering a close interplay between energy expenditure and metabolic regulation. Other factors that may explain the observed beneficial effects of cold water therapy include a healthy lifestyle comprising regular physical activity, heathy eating habits and avoidance of smoking and drinking, decreased stress levels and increased social interactions.

Potential effects of cold water therapy on cellular and molecular mechanisms of aging

Amid the growing interest in interventions that mitigate age-related decline and extend healthspan, cold water therapy is emerging as an interesting strategy. This approach draws attention to the potential capacity of cold exposure to influence cellular processes implicated in aging. In model organisms, a substantial body of literature demonstrates that lifespan can be extended by lowering temperature. For instance, studies on *Caenorhabditis elegans* [121, 122] and *Drosophila melanogaster* [123–128] have shown significant lifespan extensions under reduced temperature conditions. In these ectothermic organisms, lowering temperature slows metabolic rates, reducing the accumulation of metabolic byproducts and enhancing stress resistance mechanisms [121–132]. In *C. elegans*, lifespan extension at lower temperatures is facilitated by several mechanisms, including sterol endocrine signaling and systemic regulation of cytosolic proteostasis [121]. At reduced temperatures, *C. elegans* exhibits increased longevity through the upregulation of cold-sensing TRPA channels, maintenance of lipid homeostasis, germline-mediated prostaglandin signaling and enhanced autophagy [121, 129–132]. These processes collectively contribute to improved stress resistance and metabolic efficiency, underpinning the organism's extended lifespan under cold conditions.

However, the application of these findings to warm-blooded animals presents a more complex challenge. Endotherms, including humans, maintain a constant body temperature, which means that systemic temperature reduction is usually not feasible. A study published in 2006 reported that by lowering the core body temperature of transgenic mice by overexpressing the uncoupling protein 2 in hypocretin neurons could extend the median lifespan by up to 20% in females and about 12% in males [133]. These mice have elevated hypothalamic temperature, which modulates the central thermostat, which resulted in a 0.3 to 0.5 °C reduction of the core body temperature [133]. There is also data indicating that alterations in diurnal changes in body temperature during early life (5–19 months) can serve as a predictive marker for the remaining lifespan of mice [134, 135]. In humans, body temperature is more constant and the benefits of cold water therapy are likely mediated through localized, temporal cooling and its impact on specific cellular pathways, such as improved mitochondrial function, enhanced autophagy and reduced inflammation.

Central to the cellular aging paradigm lies mitochondrial function and the oxidative stress hypothesis [136]. Cold water therapy, through its capacity to induce hormesis [137]—a beneficial response to moderate stress—may modulate mitochondrial biogenesis and function [138]. Exposure to cold water has been postulated to enhance mitochondrial efficiency and trigger adaptive responses that confer resistance to oxidative stress [55, 104]. The activation of cold-induced pathways, such as those involving cold shock proteins [139], may bolster the cellular antioxidant defenses, potentially contributing to the attenuation of age-related oxidative damage.

The intricate interplay between chronic inflammation and the aging process underscores the significance of interventions that can minimize excessive immune activity. Cold water therapy's ability to trigger an anti-inflammatory response may hold promise in influencing immune modulation. Cold exposure is linked to altered secretion of cytokines [41, 105–107] which can potentially modulate inflammatory processes associated with aging.

The cellular recycling process of autophagy, crucial for maintaining cellular homeostasis, wanes with age [140]. Initial evidence suggests that cold water therapy may play a role in enhancing autophagy [141], thereby facilitating the removal of damaged organelles and proteins. The activation of autophagic pathways by cold exposure aligns with its potential to modulate cellular aging processes [142–144].

The sirtuin (SIR) family of NAD^+-dependent deacylases (SIRT-1, SIRT-3) play a critical role in longevity and cellular health [145]. The sirtuins might be influenced by cold exposure [146], providing another avenue through which its antiaging effects may be mediated.

Epigenetic modifications orchestrate gene expression patterns that dictate cellular function and aging trajectories. The impact of temporal cold exposure and cold water therapy on epigenetic marks, such as DNA methylation and histone modifications, warrants thorough investigation. However, it is crucial to emphasize that only chronic, regular exposure to temperature cycling (e.g. sauna) is likely to have a significant effect. This type of consistent thermal stress could potentially influence longevity-associated pathways, such as the mammalian target of rapamycin (mTOR) [147], tipping the balance towards enhanced cellular resilience and longevity. Regular temperature cycling may promote adaptive responses, improving cellular function and resistance to age-related decline.

Aging is closely related with cognitive decline, and interventions that preserve neuroplasticity are of significance. Cold water therapy's potential to stimulate the release of neurotrophic factors and enhance brain-derived neurotrophic factor (BDNF) levels [148, 149] offers a potential link to cognitive preservation. Exposure to cold stressors causes the release of cold shock proteins known as RNA binding motif 3 (RBM3) [139], which are directly linked to regeneration of synapses in the human brain [43]. Along with significant increases in levels of norepinephrine, cold water therapy also causes the release of dopamine, both which play a role in neurogenesis [44, 45].

Adverse effects of cold water therapy

While cold water therapy has attracted significant attention for its potential physiological and psychological advantages, there are potential adverse effects that can manifest from its application. These adverse effects are influenced by many factors such as age, general health condition and body size of the individual, temperature and duration of exposure to cold water therapy.

Hypothermia A condition that arises from prolonged exposure to cold temperatures is a major concern when engaging in cold water therapy [150, 151]. Submerging the body in water of excessively low temperatures can expedite heat loss, leading to a decrease in core body temperature—a precursor to hypothermia. This decline in body heat can provoke an array of adverse consequences, ranging from mild shivering to life-threatening organ dysfunction. Notably, this threat is further compounded when individuals at increased risk—such as older individuals or those with compromised thermoregulatory capacities—are involved.

Cardiovascular considerations There are cardiovascular risks while pursuing the cardiovascular benefits of cold water therapy. The abrupt exposure to cold water can induce vasoconstriction, raising concerns about undue strain on the heart and elevated blood pressure. As cold water exposure stimulates the release of norepinephrine levels [19, 37], it may also decrease the threshold for cardiac arrhythmias. Individuals with pre-existing cardiovascular conditions must exercise caution, as the rapid fluctuations in blood pressure and heart rate could potentially trigger life-threatening cardiac events such as arrhythmias and cardiac arrests [152, 153]. Cold water therapy is not recommended for patients with unstable disease, cardiac symptoms during exercise or uncontrolled arrhythmias or blood pressure.

Implications for respiratory health Cold water immersion, particularly in instances of sudden exposure, can elicit a response known as the "cold shock response", which is characterized by a sharp inhalation of air and a transient alteration in breathing patterns [152, 154]. For individuals with respiratory conditions or those susceptible to bronchospasms, this involuntary inhalation can progress into a distressing phenomenon. Asthmatics and individuals with pre-existing respiratory disorders must therefore approach cold water therapy carefully. Swimming in ice-cold water can also lead to respiratory problems such as pulmonary edema [155, 156].

Dermatological problems The epidermis, as the body's initial barrier against environmental stressors, is linked to the effects of cold water exposure. Prolonged contact with cold water can elicit adverse dermatological reactions, notably conditions such as frostbite and chilblains. There is a delicate balance between the invigorating sensations derived from CWI and the potential for epidermal trauma, which need to be carefully considered.

Other adverse effects Drinking cold water has been linked to worsened symptoms in people with achalasia [157], thickening of nasal mucus causing respiratory difficulty [158], headaches [159], tooth sensitivity and slowing of gastric emptying [160].

Optimizing cold water therapy: clinical and public health implications

Cold water therapy, while may have potential health benefits, is not a panacea for the myriad of acute and chronic conditions previously discussed. It is essential to clarify that this therapy is not being proposed as a standard remedy for the prevention or treatment of these conditions. Current evidence suggests that cold water exposure may positively impact cardiovascular and metabolic risk factors, promoting energy expenditure that could potentially mitigate the risk of chronic cardiometabolic diseases such as CVD and T2D. The therapy also induces an acute release of stress hormones, which can sharpen alertness and diminish inflammation. Moreover, the rush of endorphins it triggers can uplift mood, hinting at its potential to improve mental health conditions such as depression.

Cold water therapy may offer a holistic approach to potentially enhance both physical and mental well-being, promote healthy aging and extend the healthspan; yet, there is a need to approach with some caution. Unlike other forms of hydrotherapy and passive heat therapies, which seem to have a consistent body of evidence on their health benefits [89–94], the existing evidence for cold water therapy, while promising, is less consistent and primarily based on non-RCT studies with limited sample sizes. Furthermore, some findings are based on self-reports and there is limited data on the gender differences in the potential effects of cold water therapy. There's a pressing need for more rigorous research, including definitive RCTs, longitudinal cohort studies and in-depth mechanistic studies with objective measures.

Nevertheless, cold water therapy can be potentially integrated into daily routines to support long-term health. Regular practices such as cold showers, CWI and winter swimming can be easily incorporated into an individual's lifestyle. These practices not only promote physical health by improving cardiovascular function and reducing inflammation but also support mental well-being by alleviating stress and enhancing mood. European countries, known for their abundance of spas and wellness centers, can leverage these resources to implement public health initiatives that encourage regular hydrotherapy practices. Spas and wellness centers can play a crucial role in public health programs by providing structured environments where individuals can safely engage in hydrotherapy under professional supervision. These centers can offer educational programs, workshops and personalized hydrotherapy plans to help individuals incorporate cold water therapy into their daily routines. Such initiatives may contribute to overall wellness and longevity. Several European countries have a rich history of utilizing spas and wellness centers for health benefits, and some of these services are covered by national health insurance programs. Finland is renowned for its sauna culture, and CWI is often integrated with sauna sessions. Public health initiatives could build on this tradition by promoting regular CWI as part of a holistic wellness regimen. Currently, the Finnish healthcare system and insurance programs often cover sauna treatments as part of rehabilitative services. Germany has a well-established tradition of using spas (Kurorte) for therapeutic purposes. The German healthcare system, through statutory health insurance, often covers spa treatments, including hydrotherapy, as part of preventive and rehabilitative care. Programs promoting cold water therapy could be integrated into these existing spa treatments to enhance their preventive health measures. Switzerland also has a strong spa culture, with numerous wellness centers offering hydrotherapy. Swiss health insurance often includes coverage for certain spa treatments, particularly for rehabilitation. Hungary is known for its thermal baths and wellness tourism. The Hungarian health system supports the use of thermal waters for medical treatments, often covered by national health insurance. Integrating cold water therapy into these existing wellness practices could be a valuable addition to public health strategies aimed at enhancing healthspan.

Cold water therapy also has the potential to be integrated into rehabilitation regimens, especially for conditions like musculoskeletal injuries, as they may offer a fresh perspective on pain management. However, the science behind this therapy remains in its infancy. There are several unanswered questions, especially regarding the optimal duration and temperature to maximize benefits without risking harm given the inconsistent evidence. For recovery following high-intensity exercise or athletic performance, the current evidence seems to suggest that short- and medium-term exposure to cold water therapy at lower temperatures and within 1 h following activity is associated with more benefits. It has been reported that long-term stress is generally harmful, but short-term stress can be protective as it prepares the organism to deal with challenges [161]. However, quantification of short-, medium- and long-term stress are challenging concepts. Dhabhar defines short-term stress as lasting from minutes to hours and long-term stress as hours, daily, weeks or months [161].

Safety is paramount. As with any new regimen, it is wise to tread cautiously. Before taking up cold water therapy as a lifestyle habit, it is advisable for the individual to consult with a general practitioner to ensure it is a safe endeavor. If one chooses to engage in cold water swims, it is essential to have company and ensure the water conditions are safe. Acclimatize first and it is crucial to be aware of one's tolerance, gradually increasing the intensity and frequency of the therapy. Do not overdo it and limit the time spent in cold water, ensuring one exits before experiencing symptoms like numbness, pain or shivering. Staying in cold water for longer periods increases the risk of hypothermia. Alcohol consumption should be avoided as it is an important contributory factor to drowning [162]; it also significantly contributes to hypothermia. Preparations for warming up post-therapy are vital—having towels, warm dry clothes, a warm beverage and a sheltered spot are essential. Also engaging in warm-up exercise before and after swimming is also helpful. In summary, while cold water therapy has substantial potential for health and wellness, it is a journey that demands careful navigation. Promoting cold water therapy, through public health programs that utilize existing infrastructure such as spas and wellness centers, can support long-term health and healthy aging. By leveraging these resources, especially in countries with a strong tradition of spa use, we can enhance the healthspan of the population. However, further research is necessary to establish robust evidence for its benefits and ensure safe and effective implementation.

Future directions

The future of cold water therapy hinges on a robust research agenda that will delve deeper into its efficacy, mechanisms and individual variability. Rigorous studies, including RCTs and longitudinal investigations, are pivotal to unravelling the long-term impact and establishing evidence-based guidelines. Mechanistic studies that explore biological and molecular pathways and neurobiological responses will enrich our understanding, potentially identifying novel therapeutic targets. In the world of holistic wellness, cold water therapy may complement other treatments and therapies. From meditation and yoga to nutrition, mindfulness and hot sauna bathing, the combination of cold water therapy with these practices could amplify their respective benefits. Studies evaluating head-to-head comparisons of the different forms of cold water therapy are also warranted. The future holds promise for the targeted integration of cold water therapy within specific clinical specialties. Cardiovascular health, orthopedics, sports medicine, pain management and dermatology present potential arenas for deeper investigation.

Conclusions

Cold water therapy is emerging as a lifestyle strategy with multifaceted implications for promoting health and well-being, promoting healthy aging and extending the healthspan. Its potential to influence cellular mechanisms, prevent or reduce the severity of disease, enhance recovery and stimulate resilience is underscored by a growing body of research. However, most of the evidence is based on small sample-sized non-definitive interventional studies. Cold water therapy has the potential to be shaped into a valuable lifestyle strategy in our pursuit of health and increased longevity, but further rigorous research is needed.

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Data availability This is a narrative review; no new scientific data was generated, and all data are within the paper.

Declarations

Conflict of interest The authors declare no competing interests.

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