Whole-Body Cryotherapy in Sports Medicine

Karan Patel, MD; Neil Bakshi, MD; Michael T. Freehill, MD; and Tariq M. Awan, DO

Abstract
Cryotherapy has gained popularity among athletes across many sports. The main goals of cryotherapy, and specifically whole-body cryotherapy, are for injury prevention and counteracting negative inflammatory symptoms following athletic performance in hopes of improving recovery.

Application

Cryotherapy is defined as body cooling for therapeutic purposes. It has traditionally been performed using ice packs or cold-water immersion baths. More recently, whole-body cryotherapy (WBC) has become a popular technique of this modality. Although considerably more expensive than traditional forms of cryotherapy, WBC has become widely popular for athletes and in sports medicine. It is often used with the intention for injury prevention and to counteract inflammatory symptoms after athletic performance, thus improving recovery. WBC is typically delivered in two ways. First, an individual can stand in a chamber that is open at the top. The body and torso are exposed to frigid temperatures in the chamber, while the head remains out at room temperature. Second, an individual, or a group of individuals, may sit in a chamber that is then filled with cool air. The entire body, including the head, is exposed to frigid temperatures (Fig. 1).

WBC is performed in an environment that consists of brief exposure to extremely cold air in a custom temperature and humidity controlled cryochamber (Fig.). These chambers are maintained at −110°C to −140°C (−166°F to 220°F), depending on the specific cooling system (electrical or nitrogen). However, while the chambers are meant to cool to this temperature, due to convection from human subjects, the temperature at the skin is much warmer in human subjects (−35°C) compared with a manikin placed in the chamber (−150°C) (1). Also, individuals with a higher adiposity in their tissues tend to cool to lower temperatures (2). Prior to entering the cryochamber, each participant undergoes 30 to 60 s of temperature adaptation in a vestibule at a temperature of −60°C. During exposure, a minimal amount of clothing (shorts, socks, shoes, gloves, and a hat/headband) is worn to avoid frost bite injury. A surgical mask also is worn when the chamber includes the participant's head to avoid exhalation of humid air. Removal of sweat from each participant is required before entry into the cryochamber to avoid the risk of skin burning and necrosis. While in the cryochamber, the subjects also have to move their fingers and legs and avoid holding their breath. Exposure duration is usually 2 to 3 min (3). Selfe et al. (4) examined the effect of three different cryotherapy exposure durations in 14 professional rugby players and reported 2 min, the optimum exposure length at −135°C. This was determined based on gastrocnemius tissue oxyhemoglobin, deoxyhemoglobin, tissue oxygenation index, and skin temperature (4).

Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, MI

Address for correspondence: Tariq M. Awan, 24 Frank Lloyd Wright Dr, PO Box 391, Dominos Farms Lobby A, Suite 1000, Ann Arbor, MI 48106, DO; E-mail: awant@med.umich.edu.

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Biochemical and Physiologic Effects

Although the precise cellular mechanisms of WBC are unknown, its purported effects include decreased tissue temperature, reduction in inflammation, analgesia, and enhanced recovery following exercise (5).

Anti-inflammatory

One of the primary goals of cryotherapy is to accelerate recovery and limit inflammation after competition. Studies have demonstrated that WBC achieves this by increasing levels of anti-inflammatory interleukins and decreasing secretion of proinflammatory signaling molecules, which has been demonstrated in multiple studies (6–12). Acute and chronic elevation of IL-6 has been established to have significant proinflammatory effects. Mila-Kierzenkowska et al. (10) demonstrated that preexercise WBC prevented spikes in IL-6 in male volleyball players. Serum cytokine levels were measured at three time points: before WBC, immediately after WBC, and immediately following exercise. The control group (passive recovery) had serum levels drawn before exercise and immediately following exercise. This study demonstrated a potentially protective effect against the postinflammatory cascade following exercise. This was further supported by Ziemann et al. (8) who demonstrated that repeated WBC (5 d, twice daily) in the setting of daily exercise kept IL-6 at baseline compared to passive recovery. Ziemann et al. (7) also demonstrated in an earlier study that this same protocol of WBC (5 d, twice daily) resulted in a 60% decrease in serum

Fig 1 4/C

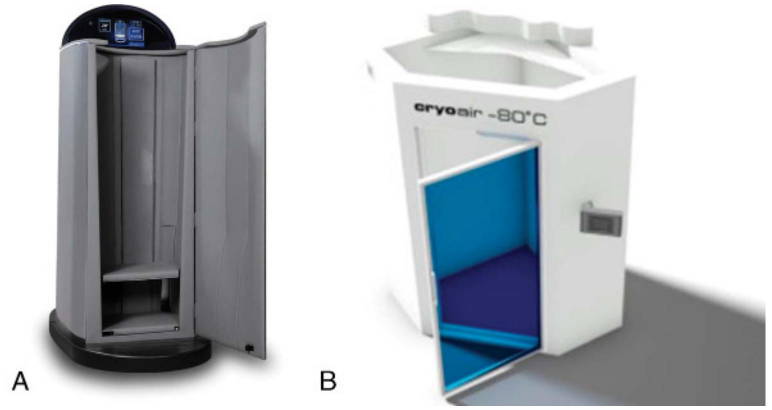

Figure: (A) WBC chamber, with head out (Image from http://www.cryousasolutions.com/product/cryosense/cryosense-configurator/). (B) WBC entire body chamber (image via http://rp-x.com/fitness/cryoair-wbc/).

TNF, compared to 35% in the passive recovery group. Blood samples in both of these studies were obtained before, and 24 h following exercise. Banfi et al. (12) also reported a decrease in intercellular adhesion molecule 1 and prostaglandin E2, corroborating the anti-inflammatory activity of WBC. The decreases in inflammatory signaling intuitively decreases pain and soreness following athletic activity, potentially allowing the athlete to recover quickly from competition.

Effects on muscle damage

Muscle activity during exercise generates oxidants inside of the cell, which are subsequently released into the intercellular space following membrane breakage which is consistent with exercise. The oxidants that are released induce other membrane damage, further increasing the concentration of oxidants in the intracellular space. This surge in reactive oxygen species induces a local inflammatory response inducing muscle damage.

WBC also may function to decrease pain and injury after athletic competition by decreasing catabolic muscle activity. The proposed mechanism includes reduction in inflammation, and therefore a potential reduction in muscle damage following exercise. Multiple studies have sought to examine this; however, the evidence is mixed (9,12,13). Increases in serum creatine kinase (CK) are associated with exertional rhabdomyolysis, and can indicate excessive physical workload and possible overtraining. Wozniak et al. reported a 34% decrease in serum total CK concentration when they examined the effect of WBC on CK levels in kayakers compared to those without WBC. They reported WBC induced a clear and significant decrease in mean values of CK (14). Banfi et al. investigated lactate dehydrogenase and CK levels in 10 high level rugby players in a passive recovery state compared to use of WBC. They found decreased levels of CK and lactate dehydrogenase with WBC compared to passive recovery. In contrast, Hausswirth et al. (13) examined CK levels in well-trained runners. They found no difference in CK levels when comparing WBC to passive recovery. While literature is mixed, there appears promise that WBC can indeed reduce muscle damage and thus enhance recovery.

Decreased bone resorption

Galliera et al. (15) reported WBC may alter the equilibrium of bone metabolism by decreasing bony resorption. This would then possess the potential to improve bone health by increasing bone mineral density. Ten professional rugby players who underwent daily sessions of WBC for five consecutive days (−110°C, 2 min) were compared with 10 players, who completed the same training protocol without WBC. Bony metabolism was measured by comparing plasma levels of receptor activator of nuclear factor κB (RANK), ligand of the receptor activator of nuclear factor κB (RANKL), and osteoprotegerin (OPG). They reported that while RANK and RANKL were not different with WBC, OPG increased significantly with WBC treatment. Osteoprotegerin is a decoy receptor for RANKL that reduces production of osteoclasts, thereby favoring bone formation over resorption (catabolism). The osteogenic potential of WBC may decrease bony catabolism and has the potential for positive effects in this regard for the athlete (15).

Hematologic cellular effects

Uncertainty remains within the literature regarding whether a hemolytic effect exists, if this is a transient finding, and whether the effect for the athlete exists. WBC has been reported to have a significant effect on hematological parameters, such as hemoglobin, total erythrocyte count, and red cell distribution width (4,16). Lombardi et al. examined the effect of WBC on erythrocytes and hematopoiesis. Twenty-seven professional rugby players underwent two daily WBC sessions at –140°C for 3 min per session for seven consecutive days. The first WBC session was before the morning practice, with the second session in the evening after the player's second practice. After 7 d, erythrocyte count (RBC), hematocrit (Hct), and hemoglobin (Hgb) decreased, with Hgb decreasing from 15.06 ± 0.84 to 14.70 ± 0.62 g/dL (16). However, Selfe et al. (4) examined these hematologic parameters for a longer period of time and found these changes to be transient. They examined two groups of 15 students from the Polish National Military Academy, with one group receiving WBC, and the other not receiving treatment. Hematological parameters were measured after 10, 20, and 30 sessions, which were performed daily (5 $d \cdot wk^{-1}$) in a cryochamber at −130°C, for 3 min. After 10 sessions, Hgb decreased from a mean of 15.1 ± 0.74 to 14.4 ± 0.94 g/dL and remained at this concentration after 20 sessions (14.5 ± 0.71 g/dL). However, it then rose to 15.1 ± 1.1 g/dL after 30 sessions. Similar changes were observed for hematocrit and erythrocyte count. This study suggests that

WBC potentially induces transient hemolysis during the initial phases of treatment. However, this hemolysis then stimulates the release of erythropoietin (EPO), which increased by 4.5% compared to baseline after 10 sessions, and by 10.8% and 10.1% after 20 and 30 sessions, respectively. The increase in EPO supports the recovery of the total erythrocyte count after the initial decrease (4). However, another explanation for this could include fluid shifts secondary to the WBC, secondary to cold induced vasodilation, as previously studied by Selfe et al. (4).

Other studies, however, have not demonstrated this hemolytic effect of WBC. Ziemann et al. examined 12 professional tennis players during a controlled training camp and reported that 10 sessions of WBC over 5 d did not affect hemoglobin or total erythrocyte count (7). Similarly, Sutkowy et al. (17) studied 16 competitive kayakers during a 19-d training regimen who underwent twice a day WBC for the first 10 d. They reported no effect on hemoglobin or total erythrocyte count at the end of the WBC course.

The effect of WBC on leukocytes also has been examined by multiple studies. Lombardi et al. and Sutkowy et al. demonstrated no changes in leukocyte counts after WBC in professional rugby and tennis players (16,17). Banfi et al. reported similar results when stratified by lymphocyte and monocyte counts in rugby players. Before and after WBC treatment, the lymphocyte count was not significantly different at 44.7 ± 8.2% and 37.8 ± 10.6%, respectively. The monocyte count also was not significantly different before and after WBC at 9.6 ± 1.7% and 9.6 ± 3.5% respectively (12). Overall, the literature remains mixed, with some studies demonstrating a transient hemolysis followed by a slow increase in hemoglobin, and other studies demonstrating no change, without any significant data suggesting change in lymphocyte count.

While at this time there is no data to suggest an increase in cardiovascular events in patients following WBC, the physiologic response must be noted. No published data investigates WBC and its effect on the clotting cascade. There are multiple studies that demonstrated an increase in both systolic and diastolic blood pressure during and following whole body cold exposure (18,19). This data can safely be applied to WBC. Caution must be taken in patients with pre-existing cardiovascular issues, as well as uncontrolled hypertension.

Hormonal alterations

Multiple studies have suggested that WBC can have an effect on systemic hormonal activity (7,17,20–23). Leppäluoto et al. (20) reported on 10 patients who underwent WBC three times per week for 12 wk. While beta-endorphin and epinephrine levels did not change over the 12 wk, norepinephrine levels increased by two to three times for all subjects immediately after a WBC session. Hausswirth et al. (22) found similar results in 15 participants who underwent single 3-min cryotherapy sessions. They reported patients had a 76% average increase of norepinephrine levels immediately after WBC. These studies suggested the increase in norepinephrine is likely a cold-induced sympathetic response, rather than a specific response to WBC.

The effects of cortisol levels on athletic performance and recovery are unclear at this time as is the response to WBC. Mixed results have been reported on the effects of WBC on cortisol levels. Grasso et al. examined 25 professional rugby players and reported decreased salivary cortisol levels after seven consecutive days of WBC (21). On the other hand, Ziemann et al. reported that cortisol levels increased in six professional tennis players treated with WBC for 5 d (7). In Sutkowy et al. (17), an examination of 16 kayakers who underwent WBC during 10 d of training, the authors reported that cortisol levels did not change significantly during the course of treatment, Smolander et al. (23) examined six healthy females for changes in pituitary and thyroid hormone levels after WBC treatments. They reported that no changes in serum concentration of growth hormone, thyroid stimulating hormone, prolactin, or free thyroid hormones were found during 12 wk of three treatment per week of WBC.

Alterations of lipid profile

WBC may have beneficial effects on lipid metabolism and may alter a subject's cholesterol profile (8,24,25). Lubkowska et al. (24) examined 69 physically active males who underwent 20 sessions of WBC over 20 d. Triglycerides significantly decreased from 108 ± 50 mg/dL to 69.4 ± 27.2 mg/dL, high density lipoprotein (HDL) cholesterol significantly increased (from 53.2 ± 16.5 to 63.1 ± 27.4 mg/dL) and low density lipoprotein (LDL) cholesterol significantly decreased (97.7 ± 48.3 to 72.8 ± 52.0 mg/dL) (24). Ziemann et al. reported similar outcomes in total cholesterol and LDL in 18 physically active males who performed 30 min of physical activity, as well as two WBC sessions per day over 5 d. The WBC group had 43% and 52% decreases in their total cholesterol and LDL, respectively (8). In a 2015 study, Lubkowska et al. (25) examined 45 overweight and obese men after 6 months of moderate aerobic activity and WBC. They reported that while body mass, body fat percentage, and lean body mass percentage did not change, LDL and triglycerides decreased, and HDL increased. Overall, the evidence suggests that WBC has a net positive effect on an individual's lipid profile.

Utilizations and Contraindications

Functional recovery

Functional recovery is defined as the return to baseline following exertion of any form in terms of strength, pain, and subjective fatigue. Several studies have examined the effects of WBC on functional recovery and performance with limited and mixed results (7,13,26–31). Hausswirth et al. and Ziemann et al. investigated the effects of WBC on functional recovery after running or sporting-based activities (7,13). Hausswirth et al. (13) found that undertaking WBC immediately and at 24 and 48 h after intense trail running resulted in significant improvements in strength, pain, and subjective fatigue compared to untreated controls. Ziemann et al. also recorded improved performance associated with WBC within a group of elite tennis players. They found that athletes incorporating twice-daily exposure to −120°C during a 5-d training camp had greater shot accuracy during two testing sessions, compared to an untreated control (7). Schaal et al. (31) found that compared to a passive control, a single WBC exposure (3 min at −110°C) enhanced subjective and metabolic recovery (based on blood lactate and $\dot{V}O_{2max}$) after intense bouts of swimming. Finally, Krüger et al. (30) examined 11 endurance athletes in a randomized crossover design during which high-intensity running was followed by WBC or placebo intervention. They reported that WBC improves acute recovery during high-intensity intermittent exercise in thermoneutral conditions (30).

Other studies, however, reported no beneficial effects of WBC for performance and functional recovery (26,27,29). Costello et al. (27) examined 36 subjects randomly assigned to WBC or placebo treatment after completion of eccentric muscle contractions. It was reported WBC had no effect on knee joint position sense, maximal voluntary isometric contraction of the knee, peak power output, or muscle soreness following eccentric exercise. A systematic review of randomized controlled trials regarding the efficacy of WBC found similar results (26). Included were four laboratory-based randomized controlled trials with no reported benefits of WBC improving muscle soreness, fatigue, or recovery (26). Fonda and Sarabon (29) also investigated the effects of WBC on functional recovery after exercise, but incorporated a more intense cooling dose at a temperature of −195°C for up to 6 d postexercise. Few significant differences between groups were found for strength and power output, however, significantly lower muscle soreness was reported with WBC.

Role in adhesive capsulitis

The clinical role of WBC in musculoskeletal pathology also has been evaluated. Ma et al. (32) examined the effectiveness of WBC in patients with adhesive capsulitis. Participants with adhesive capsulitis were randomized to receive either physical therapy or physical therapy and WBC. After 4 wk of treatment, both groups improved in terms of pain, shoulder function, and range of motion (ROM). However, the WBC group sustained significantly greater improvements in visual analog score (1.2 cm, 95% confidence interval [CI], 0.8–1.6, based on a 10-cm visual analog scale), American Shoulder and Elbow Surgeons score (four points; 95% CI, 3.1–4.9, based on a 30-point scale), and active ROM (13° abduction, 95% CI 9.2°–16.8°; 5° external rotation, 95% CI 3.2°–6.7°) (32). Chruściak et al. (33) evaluated the effectiveness of WBC in patients with osteoarthritis. They examined 50 patients with arthritis who underwent 10 d of WBC and recorded visual analog scores following treatment. They reported a significant improvement occurred in 39 (78%) patients, an improvement in nine patients (18%), and no improvement was reported by only two patients (4%). Guillot et al. (34) performed a systematic review regarding the role of cryotherapy for patients with rheumatoid arthritis. They included six studies examining a total of 257 patients with rheumatoid arthritis and showed a significant decrease in pain visual analogic scores and improvement in 28-joint disease activity score after chronic cryotherapy. They suggested cryotherapy functions to decrease intraarticular temperature with downregulation of several inflammatory and destructive joint mediators (cytokines, cartilage-degrading enzymes, proangiogenic factors).

Safety and contraindications

Due to the risks associated with extreme cold exposure, WBC should only be performed in the presence of skilled personnel. These risks include frostbite, burns, eye injury, asphyxiation, and loss of consciousness (3). Strict indications/contraindications should be utilized to determine whether a patient is appropriate for WBC. Furthermore, a consistent and well-studied protocol should be implemented to perform WBC safely. A variety of medical conditions are contraindications to WBC including; cryoglobulinemia, cold intolerance, Raynaud disease, hypothyroidism, acute respiratory system disorders, cardiovascular system diseases (unstable angina pectoris, cardiac failure in III and IV stage according to NYHA), uncontrolled hypertension, sensory neuropathies, purulent-gangrenous cutaneous lesions, sympathetic nervous system neuropathies (inability to control peripheral vascular vasoconstriction/dilation), local blood flow disorders, cachexia, previous cold injury, and claustrophobia (3). There are no specific age requirements. There are only two published complications related to WBC (aortic aneurysm, global amnesia) (35,36).

Conclusions

WBC has been increasingly utilized in sports medicine during recent years. Multiple studies demonstrate WBC has promising cellular and physiologic effects which may be beneficial after rigorous exercise and/or musculoskeletal injury (4,7,13,16,20). However, limited evidence exists regarding a definite clinical benefit to WBC. Further high quality clinical research is required to determine whether WBC can accelerate functional recovery and improve performance after demanding athletic activity. Currently, there is relatively weak, but supportive literature with regard to benefits of WBC for functional recovery following exercise, as well as protective effects when performing WBC before exercise. The role and use of WBC for recovery and prevention continues to be defined. Based on the current literature, WBC should be used as a supplement to functional recovery when the individual has no contraindications to use.

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