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REVIEWS

Cryotherapy in athletes

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Abstract

Topical cryotherapy procedures such as ice packs, cold-water immersion or cold-water ingestion have been used since ancient times to cure malaise or pain and to improve health and recovery. Since the 1970s the Japanese have invented whole-body cryotherapy, using special closed rooms where the temperature is gradually decreased by using liquid nitrogen.

In the world of sport, cryotherapy is now used in most clubs as a highly effective procedure for preparing and fostering pre-competitive athletes, for recovery after race and sport injuries, and to extend the competitive life of athletes.

Despite the numerous studies demonstrating the positive influence of cryotherapy on muscle recovery and damage, the optimal protocol remains insufficiently studied and established, and investigations are still not unanimous on the results.

More studies are required to determine the method security and to track the effects on athletic performance.

Key words: cryotherapy, athletes, recovery.

Introduction

Like other warm-blooded animals, humans can maintain their core temperature constant (at about 37°C) irrespective of the temperature variations in the air, due to a dynamic equilibrium between the two opposite mechanisms of thermoregulation: thermogenesis (heat production by cell metabolism) and thermolysis (heat loss, especially in the skin).

When exposed to an excessively hot or excessively cold microclimate, the body will try to increase thermolysis (to avoid hyperthermia) or accelerate thermogenesis (to avoid hypothermia).

Exposure to a cold microclimate stimulates peripheral thermoreceptors and puts into action mechanisms of thermoregulation: the sympathetic nervous system causes increased secretion of adrenaline with peripheral vasoconstriction (to reduce heat losses), increased heart rate and blood pressure, increased muscle contraction (about 10 contractions per second) – shivering (Liu et al., 2015). Peripheral vasoconstriction is accompanied by muscle vasodilation and blood flow is directed to the core of the body in order to preserve normal body temperature (37°C) and to sustain vital functions. Increased circulation in organs and tissues means better oxygenation, promotes a better disposal of waste (including accumulated lactate in muscle) and improves healing of muscle microlesions (Kenny & Flouris, 2014).

Reducing the skin temperature below 13°C stimulates liver metabolism and muscle reactions allowing calories burning, improves blood circulation, relieves pain, and reduces inflammation (Caldwell et al., 2018; White & Wells, 2013; Mawhinney et al., 2013).

As early as 2500 BCE, cold was used by Egyptians to treat injuries and inflammation (Freiman & Bouganim, 2005).

Frostbite and hypothermia, which can lead to death in the poorest and most fragile (homeless) individuals, are the effects of extreme exposure to cold air. Cold has been used medically since ancient times, especially in Egypt and Greece, where cold immersion was used to cure malaise or pain (Ziemann et al., 2014).

Since the 1700s, cold therapy (from the Greek 'cryo' = cold) has been used to improve health and recovery, to slow cell aging, to promote weight loss, and alleviate muscle spasms - subjects soaked in ice baths or in cold tubs (Méline et al., 2017).

Over time, cryotherapy (CT) procedures used rather topically have applied external cold, such as: ice packs (Tseng et al., 2013), ice cuffs (Pointon & Duffield, 2012), extreme cold air (Guilhem et al., 2013), ice sprays (Leicht et al., 2009), CO2 torch, alternation of cold-hot water, cooling vests (Minnet et al., 2012), cold-water immersion (4°C-15°C) of the lower part of the body (CWI) (Ingram et al., 2009; Diong & Kamper, 2013; Diong & Kamper, 2014; Stephens et al., 2017; White et al., 2014), or other combinations of these methods, such as cold-water

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ingestion (Fröhlich et al., 2014; Hue et al., 2013; Stanley et al., 2010; Tran et al., 2015); the latter procedure has led to conflicting results (Hue et al., 2013). Although local cryotherapy and immersion in cold water seem to be effective ways to fight muscle inflammation, these methods do not realize unanimity (Hausswirth et al., 2011; Hausswirth et al., 2013; Wilson et al., 2019).

Modern CT techniques consist of placing the subject in a closed room where the temperature is gradually decreased by using liquid nitrogen, allowing cryotherapy of the whole body (WBC). The Japanese invented this type of therapy in the 1970s, and cryotherapy was introduced into clinical practice (Yamauchi et al., 1981; Lombardi et al., 2017). Initially, this therapeutic method was used in the treatment of patients with multiple sclerosis or rheumatoid arthritis.

In the world of sport, the application of ice (salt batteries, cold gel, freon, dichloroethane, or other) to trauma or injury areas is a very common habit used since ancient times for pain relief and anti-inflammatory and anti-bleeding effects (Versey et al., 2013).

Limiting vascular permeability (via vasoconstriction and by slowing nerve conduction of the nociceptive message) and therefore the inflammatory process is the main beneficial effect of cold during recovery, thereby reducing muscle pain and bleeding in case of injury (Hausswirth et al., 2011; White & Wells, 2013; Mawhinney et al., 2013). The use of cryotherapy as post-exercise recovery has been increasing in popularity (Hohenauer et al., 2015; Costello et al., 2015), being an alternative to conventional therapies with ice packing (Ferreira-Junior et al., 2014).

The method consists of placing the subject in a chamber (cryoair chamber, closed rooms for one or more people) or a cabin, in which the temperature is gradually decreased to values less than minus 110°C (between -120°C and -180°C), either by using an electric cooling system or by means of liquid nitrogen, which volatilizes in contact with the skin and causes controlled cooling of the body (Hohenauer et al., 2015; Fereira-Junior, 2014). WBC is a medical practice that must be performed in specialized facilities under the supervision of well-trained personnel (Bieuzen et al., 2015).

Precautions before sessions:

- avoiding sports 30 minutes before the procedure;
- avoiding shower or hot bath 30 minutes before the procedure;
- maintaining a minimum period of 60 minutes after the last meal;
- removal of metal jewelry and piercings;
- protection of keloid scars and areas sensitive to cold.

Cryotherapy (cryosauna) can be applied to the entire body (Whole Body Cryotherapy, WBC) or on certain parts of the body, localized application (Part Body Cryotherapy, PBC). Hausswirth sustains that WBC induces a greater stimulation of the autonomic nervous system compared to PBC (Hausswirth et al., 2013). Cryosauna is used today in therapy centers, hospitals, rehabilitation and training centers, or at the users' home.

In the case of WBC, the subject is minimally dressed (e.g., bathing suit), with adequate protection of the most vulnerable parts of the body: hands, feet, nose and ears (socks, clogs, headband, and surgical mask to avoid bronchial spasm). He/she enters the vestibule chamber (at minus 60°C for about 30 seconds of body adaptation) and then passes to a special chamber, with strictly controlled temperature and humidity (-110°C to -140°C). During the entire session, the chamber door is closed. Cryogenic gas is delivered in the chamber and allows slowly lowering of the temperature up to -140°C (in 30 seconds), then the temperature remains constant. During exposure, the subject is continuosly walking with slow speed (to avoid muscle thermogenesis and so, body heating), and the breath is calm.

The duration of each procedure depends on the patient (possible illness), being generally between 1 and 3 minutes (no more than 3 minutes). The optimal number of sessions is not well established, but there is a strong correlation between the number of procedures and effects. Regarding frequency, 1 or 2 exposures daily could be enough (separated by 3 or 6 hours). The maximum effect of CT is obtained by cooling the skin to a temperature of 8-12°C (1); (2); (3).

It is important to consider some other precautions:

- It is mandatory to remove any sweat before entry to avoid the risk of skin burning and necrosis;
- Access to the chamber is allowed only in the presence of skilled personnel, supervising the procedures (visual and audio contact between patient and skilled personnel during the entire procedure is permanent);
- The entire system can be stopped at any time;
- The subject is free to leave the chamber at any time.

In France, a preliminary physical exam is demanded (skin inspection, symptoms, heart rate, blood pressure, oxygen saturation); in Switzerland, the medical certificate confirming lack of contraindications is not mandatory (Costello et al., 2015; Lombardi et al., 2017).

After CT, the subject is dressed and placed on a bed for 30 minutes, and then he/she can resume sport activities (3); (4).

When the subject leaves the cryosauna, blood vessels dilate, nutrient-rich blood flow increases, favoring in the outlying areas the healing of tissue damage and removal of toxins, and giving a pleasant and comfortable feeling. Heat shock stimulates body hardening (increases the body defenses), reduces pain, enhances joint mobility and triggers a series of reactions that lead to the release of well-being hormones such as endorphins (Rose et al., 2017).

The main accepted and unanimously validated indications of WBC are: inflammatory rheumatism (ankylosing spondylarthritis, rheumatoid arthritis), pain and sports medicine (Peake et al., 2017).

CT in athletes

WBC is now used in most clubs of the world as a highly effective way to develop and maintain a fit body; for immediately preparing and fostering pre-competitive athletes; for recovery after the race and after acute or chronic sports injuries; and to extend the competitive life of athletes (Bertrand & Mesure, 2014).

a) During the athletes' preparation (pre-cooling) at the beginning of the season, CT is effective in much faster recovery and avoids the risk of injury due to muscle fatigue

(Wozniak et al., 2007).

b) During intensive training and preparation for competitions (the 3 pre-competitive hours), WBC proved its positive influence on muscle performance (Ziemann et al., 2012). WBC positive effects on performance are due to sympathetic and parasympathetic stimulation systems, and action on the cardiovascular system, oxidative stress and the hormonal system.

- *On the cardiovascular system*, cold produces reflex tachycardia, peripheral vasoconstriction, slight elevation of blood pressure, increased systolic (but not diastolic) ejection volume, increasing muscle blood flow and oxygenation (Fonda et al., 2014).

- *Oxidative stress* is a natural response of the body when exposed to a significant effort (match, race, and workout). It reflects an imbalance between oxidants and antioxidants (overtraining syndrome). A session of WBC determines oxidative stress that is not dangerous to healthy adults. By repeating the sessions, WBC induces an adaptation of the body, increasing antioxidant defense (Lubkowska et al., 2012; Mila-Kierzenkowska et al., 2013). Studies in football, rugby and basketball players, athletes, kayakers, handball, badminton, squash and table tennis players evidenced a significant impact of WBC on reducing the recovery time (Abaidia & Dupont, 2018; Banfi et al., 2009; Chan et al., 2016; Lombardi et al., 2013).

- *Hormonal system*. WBC sessions significantly stimulate norepinephrine, a neurotransmitter synthesized by the sympathetic nervous system, increasing arousal, selective attention, vigilance and emergency reactions which are important in sports requiring prompt reflex reactions (fencing, tennis, squash) (Korzonek-Szlacheta et al., 2007).

c) In the post-competition season (Selfe et al., 2014), WBC supports recovery processes after intense physical effort. Like training, ahletes' recovery is a key factor of performance and should be planned and organized. Without thorough programming, maintaining the performance level is endangered. Suboptimal recovery of elite athletes often leads to fatigue, impairing the quality of future training sessions and/or competitive performance. A plethora of research studies the impact of cold-water immersion (CWI) and its benefits by reducing intramuscular temperature and metabolism and limiting hypoxic stress and the generation of reactive oxygen species (ROS) (Santos et al., 2012; Smolander et al., 2006).

During exercise, muscles are strained over their limit of elasticity, and induce microscopic injuries accompanied by an increase in muscle enzymes. Microlesions may go unnoticed, but over time they can lead to more serious injuries (rupture, elongation) resulting in immobilization, impossibility of training and participation in the next competition. WBC decreases blood levels of testosterone and estradiol (Korzonek-Szlacheta et al., 2007). Pournot has demonstrated a reduction of inflammatory response after strenuous long-term exercise: increased plasma concentrations of anti-inflammatory cytokines and decreased pro-inflammatory cytokines (Pournot et al., 2011). Broatch maintains that post-exercise cold-water immersion benefits are not greater than the placebo effect (Broatch et al., 2014).

Intense exercise is a stress to the body and can cause delayed onset muscle soreness (DOMS) and alter the markers of muscle damage (increasing the blood levels of several muscle proteins such as creatinine kinase and myoglobin), especially during running or cross-country skiing. Exercise-induced muscle damage negatively impacts performance, so many scenarios of recovery techniques have been imagined: physiological and nutritional approaches, massage, active recovery (ACT) and cryotherapy.

Lindsay Angus (Angus et al., 2017) conducted a research on combative sports athletes (MMA - mixed martial arts, one of the most physically intense forms of exercise), who might benefit from cold-water immersion that reduces DOMS as well as the hypothalamic-pituitary axis and macrophage activation without impairing functional performance.

Adam has demonstrated that WBC applied after intense exercises (one session of WBC at one hour post-exercise is strongly recommended) has a positive influence on muscular recovery and damage (Adam, 2014), improving healing of microlesions, the effect being maintained for another 2 hours after the session. Also, WBC limits the increase in muscle enzymes produced by intense effort (Costello et al., 2012; Costello et al., 2015), but the results are ineffective if WBC is applied 24 hours after strenuous exercise, without any improvement in muscle strength.

In a research on 9 highly trained runners, Hausswirth and coworkers (Hausswirth et al., 2011) found that cryotherapy is a more efficient post-exercise recovery strategy than far infrared (FIR) or passive (PAS) modalities of muscular recovery: maximal muscle strength was recovered 1h after the WBC session, 24h after FIR and was not attained through the PAS technique.

Other researchers have demonstrated that WBC improves sleep quality (Schaal et al., 2013; Bouzigon et al., 2014; Miller et al., 2012; Mila-Kierzenkowska et al., 2009), sleep being important in the recovery process, along with nutrition and hydration.

There are two variants of recovery cryotherapy, always in combination with other therapies (medical, physiotherapy): the first option consists of a single use of the cryogenic cabin after exercise; the second is the use of cryotherapy daily or twice daily, for a period that does not exceed three weeks, leaving a three month break between courses.

Treatment includes 10, 20 or more procedures. Preventive procedures can be carried out daily or every 2-3 days. The frequency of procedures for the treatment of rheumatic diseases or other conditions may increase to 2/ day (with 6 hours between procedures).

Other effects of CT

- WBC causes *some blood effects*: decreases in hemoglobin (Hb), hematocrit (Ht) and red blood cells (RBCs) after 5, 10, and 20 sessions, with recovery of hemoglobinization after 30 sessions; leukocytes either slightly increase or do not change, while platelets are not affected (Hausswirth, 2011; Roberts et al., 2015). Another study (Lombardi et al., 2013) demonstrated changes in the hematological profile of professional rugby players,

after 5 sessions of WBC, five days in a row. However, this study did not have a control group, so it is difficult to discern whether the effects were due to cryotherapy or the cumulative effects of training (Méline et al., 2017).

- *Stimulates the autonomic nervous system* (parasympathetic) and decreases the heart rate (Hausswirth et al., 2013).

- *Increases aerobic capacity* (Schaal et al., 2013). It is well established that, with intensified exposure to cold, oxygen consumption increases. For example, the increase in oxygen consumption under the influence of a cold bath of 25 kcal/m2 is 27-30%, and with a cold air bath of 45 kcal/m2, it reaches 48-53% (Boujezza et al., 2018).

- *Improves metabolism* by increasing mitochondrial biogenesis (2 sessions of 5 minutes at -8°C are sufficient) (Joo, 2016).

- Local cryotherapy is used for *weight loss* by stimulating fat metabolism (Dulian et al., 2015). It uses temperatures between -2°C and -4°C in sessions of up to 3 minutes. Cryolipolysis destroys up to 80% of the fat cells which can not be removed by other methods.

- Cold therapy causes an *after-effect*, obvious after one treatment cycle. It consists of favorable changes in biochemical indices a long time after exposure to the hardening treatment, in some cases after a few months or even a year. The real situation in the body is characterized by a rhythmic oscillation of vasoconstriction and vasodilation of the skin, thus preventing ischemic damage to tissues (Abaidia & Dupont, 2018; Elias et al., 2012).

Cooling efficiency and, possibly, treatment effectiveness can be influenced by body composition. Due to differences in body composition, cooling efficiency is potentially greater in females than in males (Hammond et al., 2014).

Other uses of cryotherapy

Therapeutic indications of CT are numerous: Rheumatology, Hepatology, Neurology, Cosmetology, Sexology and Urology, Endocrinology, Pulmonology, Cardiology, Dermatology, Orthopedics and Traumatology. Aircryotherapy (ACT) is very effective in recovery from chronic fatigue syndrome, or as a treatment of depressive states. Under the influence of ACT, irritability disappears, the person becomes enthusiastic, and the desire to consume alcohol or sedatives decreases. Objectively, tremor is reduced and autonomic responses (sweating, dystonia) decrease in intensity. Virtually all patients gain health, their performance increases and their sex life improves.

A recent study (Akiko et al., 2017) found that cryotherapy, specifically having chemotherapy patients wear frozen gloves and socks for 90-minute periods, is useful for preventing symptoms of neuropathy (a frequent and disabling side effect of cancer treatment).

Contraindications of CT

Currently accepted contraindications for WBC include: cryoglobulinemia, agammaglobulinemia, cryofibrinogenemia, cold intolerance, Raynaud disease, hypothyroidism, acute respiratory system disorders, cardiovascular system diseases (unstable angina pectoris, cardiac failure stage III and IV), purulent-gangrenous cutaneous lesions, sympathetic nervous system neuropathies, local blood flow disorders, cachexia, hypothermia, claustrophobia and mental disorders hindering cooperation with the patient during treatment; stroke, fever, active pulmonary tuberculosis, malignant tumors, bleeding diathesis, severe anemia, hypothyroidism, hysterical neurosis, individual intolerance to cold, cold urticaria, pregnancy, open wounds, drugs, as well as subcutaneous devices (Selfe et al., 2014).

Some relative contraindications also exist: age above 65 (WBC is popular among those aged over 65; age is not a serious contraindication if other more important contraindications do not occur), venous thrombosis and a history of peripheral arterial embolism, and excessive emotional lability (Lubowska et al., 2012; Sieroń et al., 2007).

In children, the precautionary principle is applied (Lubowska et al., 2012) because of thermoregulatory vascular reactions and their effects on cartilage growth, making this method contraindicated in growing patients (under 18 years of age).

When performed under appropriate and controlled conditions, WBC is considered a safe procedure, which was demonstrated to be deleterious neither for lung nor heart function (Banfi et al., 2009). Smolander showed the effects of WBC on lung function, causing moderate bronchoconstriction, which raises caution about its use in asthmatics (Smolander et al., 2006).

However, recorded observation of a very slight, clinically irrelevant increase in systolic blood pressure (Lubkowska et al., 2010; Lubkowska & Suska, 2011) justifies precautions indicated for patients affected by cardiovascular conditions.

Side effects of CT

To date, there are insufficient studies to prove CT effectiveness regarding pain reduction or muscle recovery. Too few studies have been conducted on possible adverse effects despite the precautions taken by cryotherapy centers. Some studies have revealed cases of frostbite, while others were not interested in other potential damage to the body.

Hohenauer considers that currently, the effects of cryotherapy on recovery through DOMS, blood plasma markers (including cytokines), performance parameters and the Borg scale (Hohenauer et al., 2015; Krueger et al., 2019) are often unclear in humans.

A group of four specialists in Northern Ireland, France and Australia conducted a series of studies on cryotherapy. According to them, there is little medical evidence that this method really contributes to functional recovery of athletes, and studies have not taken into account the active surveillance of subjects in terms of side effects. The risks can be fatal if exposure takes place without specialized supervision (5).

Conclusions

1. Physical effort is a stress for the body; athletes are prone to injuries and pain. Insufficient recovery after exhausting physical effort can often lead to fatigue, delayed recovery and reduced competitive performance. WBC seems to be a more comfortable, modern and effective

alternative to cold-water immersion, proposed to reduce pain, inflammation, and muscle soreness.

2. Studies on the effects of cryotherapy in athletes are essential both to determine the security of the method and to track its positive or negative effects on athletic performance. It must also be checked whether cryotherapy could mask a doping product or would entail effects that might give the impression that the athlete uses doping products.

3. Cryotherapy proposes many benefits and has become one of the latest trends for athletes and professional teams, clinicians, trainers, as well as for some celebrities. It is considered a helpful approach to muscle recovery, in addition to other recovery techniques: massage, nutritional and physiological approaches, and active recovery. Although the optimal protocol remains insufficiently studied and established, and investigations are still not unanimous on the results, CT could be helpful in healing and relieving pain from muscle or joint inflamation, in improving sleep quality, in recovery after extreme stress and effort. The field of cryotherapy needs to be deepened, many publications showing beautiful perspectives of this method.

Conflict of interest

Nothing to declare

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