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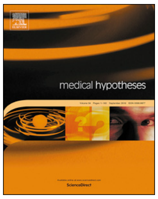

Should whole body cryotherapy sessions be differentiated between women and men? A preliminary study on the role of the body thermal resistance

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ABSTRACT

The aim of this study was to investigate how body thermal resistance between sexes evolves over time in the recovery period after a WBC session and to show how this parameter should be considered as a key parameter in WBC protocols. Eighteen healthy participants volunteered for the study (10 males and 8 females). Temperature (core and skin) were recorded pre- and post (immediately and every 5 min until 35 min post) exposure to a single bout of WBC (30 s at −60 °C, 150 s at −110 °C). From both core and skin temperatures a bio-heat transfer model was applied which led to the analytical formulation of the body thermal resistance. An unsteady behavior presenting a similar time-evolution trend in the body insulative response is shown for both females and males, possibly due to the vasodilatation process following an intense peripheral vasoconstriction during the extreme cold. Females present a 37% higher inner thermal resistance than males when reaching an asymptotical thermal state at rest due to a higher concentration of body fat percentage. Adiposity of tissues inherent in fat mass percentage appears to be a key parameter in the body thermal resistance to be taken into account in the definition of appropriate protocols for males and females. The conclusions of this preliminary study suggest that in order to achieve the same skin effects on temperature and consequently to cool efficiency tissues in the same way, the duration of cryotherapy protocols should be shorter when considering female compared to male.

Introduction

Whole-Body Cryotherapy (WBC) is a widely used treatment to help alleviate muscle soreness, depression, rheumatic conditions, ankylosing spondylitis, inflammatory symptoms and also to contribute to enhance muscular recovery [1,2]. In sport medicine, the use of cryotherapy has become widespread in recent years, and numerous studies in the literature have investigated the benefits of cryotherapy for athletes [3–5]. However, upon critical examination of most of these studies concerns over the empiricism of the protocols used, especially concerning relative dosage, temperature and duration tend to arise. Given that WBC may have many methodological issues it is surprising that these protocols are not differentiated between the populations studied, particularly with regard to the sex of the participants.

WBC consists of exposing patients to extreme cold air (−110 °C) in minimal clothing, during a short time duration (2–4 min). The thermal shock monitored by skin peripheral thermoreceptors induces complex thermoregulation responses via the central nervous system to maintain constant the temperature of vital organs raising physiological barriers against the extreme atmosphere [6]. The skin which is the largest organ of the body is the link between internal tissues and the environment. The dynamics of skin temperature during WBC depends on two factors, the thermal gradient between body and external environment and tissues capacity to attenuate the heat losses from the body's core to the skin. These two factors are subject to modification when the body is exposed to such an extreme temperature. The latter factor is more complex to evaluate because it takes into account numerous elements such as deep tissues adiposity, skin and muscle blood flow; which ultimately contribute to the thermal resistance. This thermal resistance expresses the thermal insulation of human tissues and is inversely

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proportional to thermal conductivity. The higher the thermal resistance, the greater the insulative response is and given that tissue cooling and transfer depends on several factors relative to sexual dimorphism (body fat), it may seem prudent to suggest that males and females insulative capacity may differ. The difference in body fat, which acts as insulation, ultimately may increase heat storage. Theoretically, the more vasoconstriction occurs due to such a cold exposure, the greater the magnitude in change of skin temperature. The change in skin temperature following WBC relative to sexual dimorphic differences has received little attention in the literature [7,8]. Effectively, the paucity of data in this field begs the question of how do sex related differences affect thermal resistance after WBC?

Therefore, the primary aim of this study was to investigate how the thermal resistance between males and females alters during the rewarwing period after a WBC session. A subsequent secondary aim of this study was to apply a bio-heat transfer mathematical model to test the hypothesis and to obtain a predictive blueprint of appropriate WBC protocols between sexes [9].

Hypothesis

In view of the lack of research on the gender influence on the WBC protocols, the aim of the current study was to investigate how body thermal resistance between sexes evolves over time in the recovery period after a WBC session and to show how this parameter should be considered as a key parameter in WBC protocols. It was hypothesized that adiposity of tissues inherent in fat mass percentage appears to be a key parameter in the body thermal resistance to be taken into account in the definition of appropriate protocols for males and females.

Methods

For the sake of conciseness, the reader is directed to a recent article for the details of the experimental, medical and administrative procedures of the current study [10]. Briefly, ten healthy young male (age 27.7 ± 6.9 years, height 1.82 ± 0.07 m, body mass 78.8 ± 13 kg, lean mass 68,5 ± 8,6 kg, body fatness 13.7 ± 6.9%, body surface area (BSA) 1.9 ± 0.1 m^2, BSA to mass ratio 2.5 ± 0.1 cm^2/kg) and eight young female (age 27.6 ± 6.3 years, height 1.63 ± 0.08 m, body mass 62.5 ± 7.7 kg, lean mass 46,1 ± 7 kg, body fatness 26.2 ± 5.4%, body surface area (BSA) 1.6 ± 0.1 m^2, BSA to mass ratio 2.6 ± 0.1 cm^2/kg) were recruited for the present study. Mean core (T_c) and skin (T_{sk}) temperatures for both male and female volunteers groups are given in Table 1. For this purpose, core (rectal) temperature was recorded after the participants self-inserted a thermistor (Grant Instruments, Cambridge, UK), ~10 cm beyond the anal sphincter. Skin temperature was recorded using a FLIR Thermal Imaging Camera (E40BX FLIR systems, Dandeyd, Sweden).

Table 1
Core (Tc) and skin (Tsk) temperatures of study participants (mean and SD) in the rewarming after −110 °C WBC.

Time (min)	0	5	10	15	20	25	30	35	∞
FEMALES									
Mean Tc (°C)	37.5	37.5	37.5	37.4	37.3	37.3	37.3	37.2	37.3
SD (Tc)	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.3
Mean Tsk (°C)	19.61	27.24	28.98	30.03	30.79	31.16	31.48	31.76	33.18
SD (Tsk)	2.40	1.26	0.50	0.21	0.28	0.22	0.14	0.19	0.41
MALES									
Mean Tc (°C)	37.5	37.5	37.4	37.3	37.3	37,2	37.1	37.1	37.4
SD (Tc)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Mean Tsk (°C)	22.19	28.90	30.45	31.19	31.74	32.02	32.33	32.52	33.52
SD (Tsk)	2.29	1.58	0.91	0.62	0.60	0.46	0.42	0.42	0.59

The study was approved by the Moulton College Human Research Ethics Committee and, in accordance to the Declaration of Helsinki, participants were informed of the requirements of the study prior to signing a consent form. Moreover, each participant also completed a medical consent form and declared that they were free from medical conditions including Raynaud's phenomenon and other cold sensitivities, heart conditions, claustrophobia, and allergy to adhesive tape.

Following a safety briefing from the chamber (Cryogenic chamber; JUKA Poland) operators, participants were required, in pairs, to enter the antechamber for 30 s at −60 °C, and transferred through an internal door to the main chamber for 2 min at −110 °C [10]. Following WBC exposure, participants transferred immediately to the adjacent laboratory to capture the post WBC data.

Results

The thermal resistance of the human body is difficult to estimate because of complex anatomical and physiological factors. In the formulation used, the thermal resistance depends on the unsteady heat storage level and also on the moving boundary between deep tissues and skin, namely due to vasodilatation. The bio-heat transfer model is based on an electrical analogy in which heat flux density is associated with electric current, temperature difference with potential difference and electrical resistance with thermal resistance (Fig. 1). In such a way, the thermal resistance (R_b) takes into account both the tissues resistance between body core and skin (R_{tissue}) and the blood flow thermal resistance (R_{blood}). The corresponding core-to-skin conductance combining these parallel resistances can be expressed as [11]:

$$\frac{1}{R_b(t)} = \frac{1}{R_{tissues}} + \frac{1}{R_{blood}(t)} \tag{1}$$

The thermophysical parameter that characterizes the propensity of a material to transfer heat is thermal conductivity. For example, the conductivity of fat is 0.21 W/mK while that of blood, considered as the heat transfer fluid of the human body, is 0.52 W/mK. The ratio between these values shows that, even if blood and the associated induced actions of vasoconstriction and vasodilation have a major effect on the body’s thermal response to a thermally extreme atmosphere, fat tissues nonetheless seem to have a significant effect [12,13].

Thermal analysis

Bio-heat transfer modeling of the human system aims to calculate the properties of heat transfer thermal exchanges between the human body and its environment, on the basis of a general heat balance [11]. At rest following a cryotherapy session (without conduction, evaporation), the heat balance is maintained when the rate of heat production φ_{met} (metabolism) is equal to the heat lost by radiation φ_{rad}, convection φ_{conv} and respiration φ_{resp} (Fig. 1) provided that the storage effects are neglected, which can be assumed for a low variation of core (rectal) temperature.

The human body can be considered as a weakly unsteady thermal system so that the conservation of the thermal rate is satisfied leading to the following set of equations:

$$\begin{cases} \varphi_{met}(t) = \varphi_{conv}(t) + \varphi_{rad}(t) + \varphi_{resp}(t) \\ \varphi_{met}(t) = \frac{(T(t)_c - T(t)_{Sk})}{[BSA]R_b(t)} \end{cases}$$

where $T_c$is the core temperature, $T_{Sk}$is the skin temperature, BSA is the Body surface Area and $\varphi_{resp}(t)$ is the sum of latent respiration heat loss and dry respiration heat loss. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) rules give the following equation for total respiratory heat loss [14]: