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Actual temperature during and thermal response after whole-body cryotherapy in cryo-cabin

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ABSTRACT

Whole-body cryotherapy (WBC) involves exposing minimally dressed participants to very cold air (injecting liquid nitrogen with temperature −195 °C), either in a specially designed chamber (cryo-chamber) or cabin (cryo-cabin), for a short period of time. The aim of this study was to examine the actual temperature of the air in the cryo-cabin at different locations throughout the cabin by using human subjects and a manikin. Additionally, we monitored skin temperature before and for 60 min after the cryo-cabin session. Twelve subjects completed one 3 min cryo-cabin session. Temperature next to the skin was assessed during the session, while the skin temperature was monitored before, 3 min after and every 10 min for 60 min after completing the session. There was a statistically significant interaction (time × position) for temperature among the different body parts during the WBC, and for skin temperature among different body parts after the cryo-cabin session. Statistically significant time effects during and following cryo-cabin session were present for all body parts. We showed that actual temperature in the cryo-cabin is substantially different from the one reported by the manufacturer. Thermal response after cryo-cabin session is similar to response observed after cryo-chamber cold exposure reported in previously published studies. This could be of great practical value as cryo-cabins are less expensive and easier to use compared to cryo-chambers.

1. Introduction

A reasonably new form of cryogenic therapy, called whole-body cryotherapy (WBC), has been offered to athletes as an alternative to cold water immersion or other cold exposures (Banfi et al., 2010). WBC involves exposing minimally dressed participants to very cold air, either in a specially designed chamber (cryo-chamber) or cabin (cryo-cabin), for a short period of time. The exposure to cold air usually lasts up to three minutes. Low temperature is regulated by repetitive short (1–5 s) injections of liquid nitrogen, which at atmospheric pressure boils at −196 °C. The temperature in the cabin or chamber is not constant as the human body works as a source of warm temperature. Therefore, the nitrogen is injected when the temperature in the cabin or chamber falls below a set value (e.g. −140 °C for cryo-cabin). However, it is important to note, that the point of temperature measurement is not necessarily inside the chamber but at the point of nitrogen injection.

In medicine and sports, WBC has gained wider acceptance as a method to improve recovery from muscle injury (Hausswirth et al., 2011; Pournot et al., 2011), degeneration and inflammation of joints (Ma et al., Kim), etc. Apart from WBC, it has been shown that locally applied cryotherapy reduces cell necrosis and neutrophil migration, as well as slowing down cell metabolism and nerve conduction velocity, which in turn reduce secondary tissue damage (Wilcock et al., 2006). According to Kleiber's law metabolic rate would have to be 7 times higher in cryogenic conditions (Cholewka et al., 2004). Decreased tissue temperature stimulates cutaneous receptors to excite the sympathetic adrenergic fibres, causing the constriction of local arterioles and venules. This results in a reduction of swelling and a decreased rate of metabolism, which sequentially attenuates the inflammatory response, vascular permeability and the formation of oedema (Cheung et al., 2003; Paddon-Jones and Quigley, 1997). To the authors' knowledge, there is no general conclusion on the amount of tissue temperature drop resulting from the aforementioned physiological effects.

It has been previously reported that skin temperature drops down to approximately 5.2 °C in the forearm and calf, while mean skin temperature drops to approximately 12.4 °C during WBC in a cryo-chamber (Westerlund et al., 2003). Westerlund et al. (2003)

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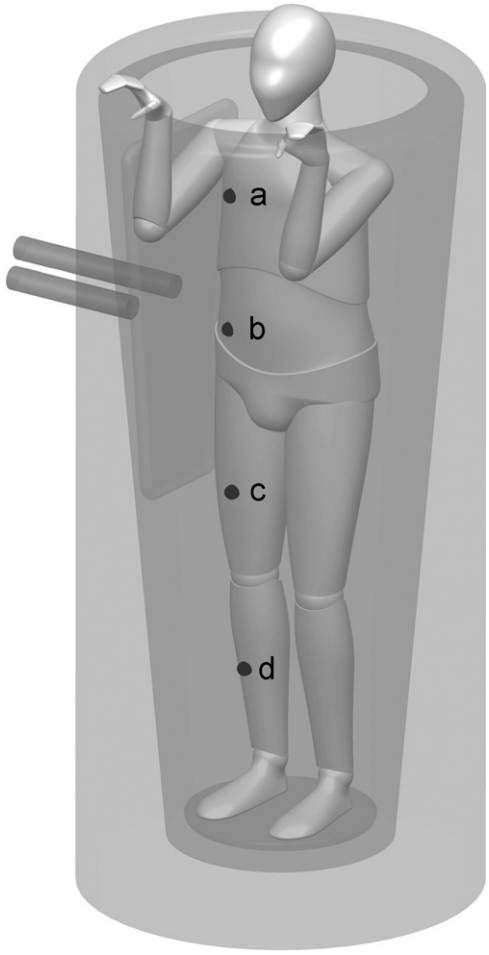

Fig. 1. Position of the subject in the cryo-cabin and positions of the sensors. Subject was instructed to turn around continuously. Sensors positions: (a) chest; (b) trunk; (c) thigh and (d) shank.

also monitored skin temperature 30 min after the WBC and reported that skin temperature increases rapidly after WBC, but does not reach baseline even after 30 min. Cholewka et al. (2012) used thermal imaging to monitor changes in skin temperature and showed a difference of approximately 8 °C after WBC in a cryo-chamber compared to baseline. All studies examining thermal response after WBC used a cryo-chamber, while thermal response after WBC in a cryo-cabin remains unknown.

To the authors' knowledge there is no study that has examined the actual temperature that the skin reaches in a cryo-cabin. Cholewka and Drzazga (2006) reported that temperature in a cryo-chamber during therapy is between 67 and 125 °C and varies in respect to height. Furthermore, on a model Cholewka et al. (2005) showed that temperature 3 mm under the skin falls to approximately −17 °C when cryo-chamber is set to −120 °C. Liquid nitrogen in a cryo-cabin is normally injected from one point which means that the distribution of cold air is not even throughout the cabin. Additionally, real time temperature that is displayed on the cryo-cabin is measured at the point of injection and not inside the cabin (Fig. 1).

The first aim of this study was to monitor actual temperature of the air in the cryo-cabin at different locations throughout the cabin. Additionally, the majority of studies on thermal response have been conducted using only cryo-chambers, while data on cryo-cabins is scarce. Hence, the second aim was to monitor skin temperature for 60 min after the WBC in a cryo-cabin. Our hypotheses were that (1) temperature next to the skin will differ among different body regions, (2) temperature next to the skin will be substantially higher than temperature displayed by the manufacturer, (3) skin temperature will significantly drop after WBC, and (4) skin temperature after WBC will vary among different positions.

2. Materials and methods

2.1. Participants

Twelve healthy young male adults ([mean ± SD], age 26.8 ± 5.5 years, height 181.3 ± 6.1 cm and weight 79.7 ± 8.7 kg) were recruited for this study. Participants were requested not to eat, smoke, and drink alcohol or hot drinks for 4 h before the experiment. An interview, during which the details of the study were presented, was carried out prior to the start of the experiment. The study was approved by the National Medical Ethics Committee and all participants signed a statement of informed consent at enrolment.

2.2. Active measurements

Each participant arrived to the laboratory 30 min before WBC, to acclimate to the room temperature (25 ± 1 °C). Before the WBC exposure, four Pt-100 resistance thermometers connected to the switch system (Keithley 7001, Keithley Instruments, Inc., USA) and to the NanoVolt/MicroOhm Metre (Agilent 34420A, Agilent Technologies, Inc., USA), were placed on the participant. Temperature sensors were placed on the middle of the tibia, middle of the thigh, lateral to the belly button and over the sternum (Fig. 1). All temperature sensors were placed on the front right side of the participant. Extra isolating layer of fabrics was placed between the sensor and the skin in order to measure the atmospheric temperature next to the skin and not the skin temperature. Sensors were fixed to the body with net tubular bandage. Contralateral to temperature sensors, spots were drawn with permanent marker on the same anatomical sites. After that, measures of skin temperature with a non-contact thermometer (Land Cyclops 300af, Minolta Co., Ltd., Japane) were taken from the marked sites. Additionally, thermal imaging of the whole body from front and back was performed using a thermal camera (Mob®RI M4, Wuhan Guide Infrared Technology Co., Ltd., China). Non-contact measurements were executed from 0.5 m distance with emissivity set to 0.97, while thermal imaging was completed from a distance of 6 m with the emissivity set to the 0.97 (Jones and Plassmann, 2002).

Each participant was then exposed to low temperatures for three minutes (from −140 to −195 °C) using cryo-cabin (Space Cabin, Criomed, Ltd, Kherson, Ukraine). Three-second long injections of liquid nitrogen were done every time the temperature in the cabin rose above −140 °C. According to the manufacturer's recommendations, each participant had their feet protected with warm shoes, hands and head outside of cabin and had to turn around continuously in the cabin.

Immediately after the WBC session, temperature sensors were removed from the body and the measurements of skin temperature were performed. These measurements were then repeated 3, 6, 9, 12, 20, 30, 40, 50, and 60 min after the WBC. Between the temperature measurements participants sat on a chair in the room with temperature (25 ± 1 °C). Participants were instructed not to talk, eat, drink or do anything that could influence the thermal response.

Data from the thermal imaging camera was interpretted with commercially available software (Ir Analyser, Wuhan Guide Infrared Technology Co., Ltd., China). Skin temperatures from

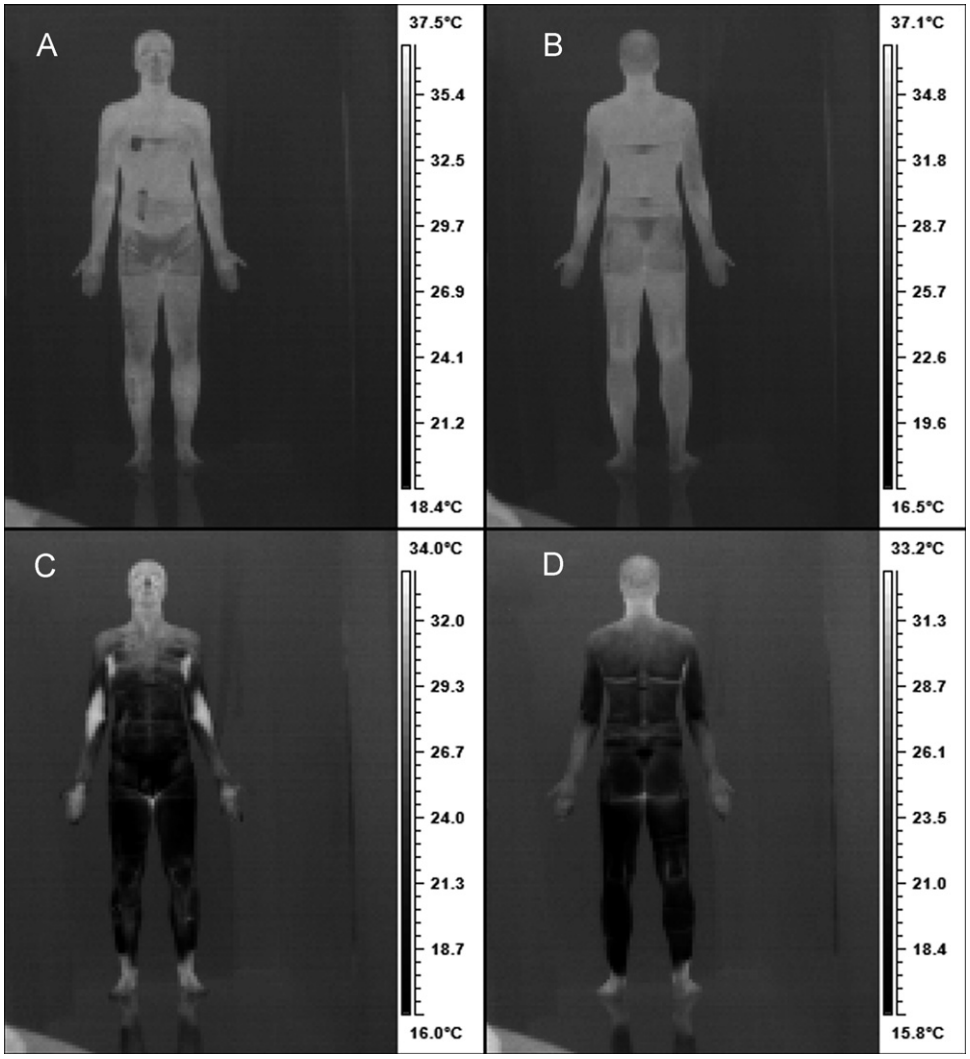

Fig. 2. Examples of thermal imaging before (A, front and B, back) and immediately after the WBC (C, front and D, back).

thermograms were read as mean values on the area of shank, thigh, stomach, chest and upper arm (Fig. 2). Shank, thigh and upper arm values were taken as mean of left and right side.

2.3. Passive measurements

One passive measurement, with two temperature sensors inside, was performed in an empty cryo-chamber. One sensor was placed next to the sensor provided by the manufacturer (at the point of liquid nitrogen injection), while the other one was in the middle of the cabin. Additionally, four measurements were performed with four temperature sensors attached to a manikin at the body regions as for active measurements. The manikin was made out of Styrofoam matching the volume and size of a regular male subject with a height of 180 cm and a weight of 75 kg. For every measurement, the manikin was rotated 90° (Fig. 5). The protocol of WBC for passive measurements was identical to that for active measurements.

2.4. Statistical analysis

For each of the measured parameters, means and standard errors were calculated. The Shapiro–Wilk test was used to test for the normality of the distribution. In order to exclude variations in the baseline values, we calculated the differences in temperature

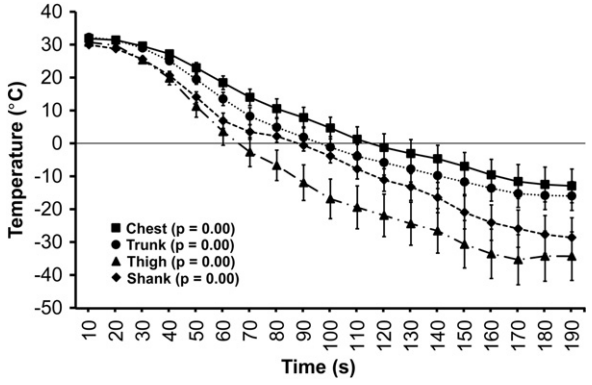

Fig. 3. Profile of the temperature next to the skin during whole-body cryotherapy.

after WBC compared to baseline. A Two-way repeated measures ANOVA was used to test these relative values for significant differences among all four body regions/sites, throughout the time. Body region was the inter-subject factor and time was the intra-subject factor. Before that, Mauchly's test of sphericity was performed and appropriate corrections were used when significant ($p < 0.05$). Additionally, for every measured parameter, repeated measure ANOVA and *post-hoc* t-tests with Bonferroni

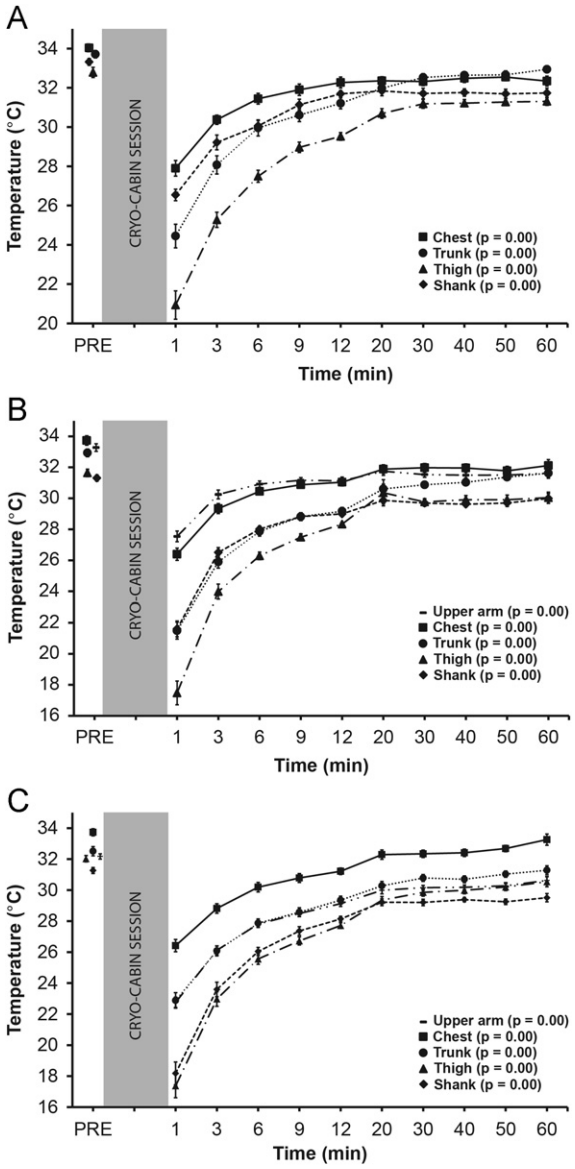

Fig. 4. Skin temperature profiles measured with non-contact thermometer (A) and thermal imaging from the front (B) and back (C). *P*-values represent time effects measured with repeated measure ANOVA for each body region.

correction were calculated from absolute values. The level of significance for all tests was set at $p < 0.05$. All statistical analyses were performed using the IBM SPSS statistics 20.0 software (Armonk, NY, USA).

3. Results

There was a statistically significant interaction (time × position) for temperature among the different body parts during the WBC ($p=0.000$; $F=2.889$; $Eta=0.224$). Statistically significant time effects were present for all body parts (Fig. 3).

Statistically significant interactions were observed for skin temperature among different body parts after WBC, measured with the non-contact thermometer ($p=0.000$; $F=23.084$; $Eta=0.677$), thermal imaging camera from the front side of the subject ($p=0.000$; $F=39.104$; $Eta=0.780$), and with thermal imaging camera from the back side of the subject ($p=0.000$; $F=35.904$; $Eta=0.765$). Statistically significant time effects were present for all body parts (Fig. 4).

4. Discussion

The aims of this study were to monitor actual temperature of the air in the cryo-cabin and additionally skin temperature for 60 min after the WBC. All our four hypotheses have been confirmed as (1) temperature next to the skin significantly differed among different positions, (2) temperature next to the skin was substantially higher than temperature displayed by the manufacturer, (3) skin temperature had a significant drop after WBC, and (4) skin temperature after WBC was significantly different among positions.

Manufacturers of cryo-cabins usually provide real-time feedback on the temperature inside the cabin. This temperature is measured at the point where liquid nitrogen is being injected and therefore does not provide the information on actual temperature throughout the cabin. We suspected that due to the convection from a human body to the air in the cabin, the temperature may rise even more. Results of our study confirmed these hypotheses, as a mean temperature in the cabin was substantially higher than the temperature displayed on the cabin. The lowest temperature recorded was at the end of the 3 min session on the thigh (−35 °C). We also observed significant differences among body regions throughout the session. Interestingly, the lowest temperatures were recorded on the thigh followed by the shank, trunk and chest, respectively. To the authors' knowledge this is the first study that examined the air temperature in the cryo-cabin during WBC. Cold air has higher density than warm air, which means lower parts of the cryo-cabin are colder then upper. This fact has been confirmed with measured lower temperatures in the lower part of the cabin during the therapy.

Temperature in a cryo-cabin with a manikin inside dropped lower (−150 °C) compared to the measurements with real subjects, which confirms the fact that air in the cryo-cabin drops less in temperature due to the convection from the subject. These observations indicate that human body metabolism should be taken into account when setting the temperature for cryo-therapy/session. Substantial differences were observed among measurement sites (Fig. 5). This is why it is important to instruct subject to turn around, to insure more equal cold exposure to all body parts. We observed consistent fluctuations in temperature which are in line with the rate of nitrogen injections. The lowest temperature on the manikin was observed from the sensor placed on the shank, which is contrary to the measurements with real subjects where the lowest temperature was observed on the thigh. This could possibly be due to the warm shoes subjects wore during the cryo-cabin session and their influence on heat distribution of the lower part of the legs. The second reason for that could be the position of the nozzle (Fig. 1) which is in average in the height of the trunk (depends on subject's height) (Fig. 6).

Thermal imaging is a noninvasive technique that provides information about skin temperature distribution, which can be related to blood perfusion. It has been found to be an accurate and reliable method to asses skin temperature after cryotherapy (Costello et al., 2012). Thermal response after WBC has already been examined by means of thermal imaging (Cholewka et al., 2006, 2012; Westerlund et al., 2003). Cholewka et al. (2012) reported differences in skin temperature immediately after WBC in a cryo-chamber similar to the one we found after WBC in a cryo-cabin. The thermal response we observed in the first 30 minutes measured by the thermal imaging and by the non-contact thermometer are in line with the thermal response reported by previous studies using cryo-chambers (Cholewka et al., 2004; Westerlund et al., 2003). However, Westerlund et al. (2003) reported the lowest temperatures for calf and forearm, while we observed the lowest temperatures for thigh and trunk. This is interesting as temperature inside the cabin was

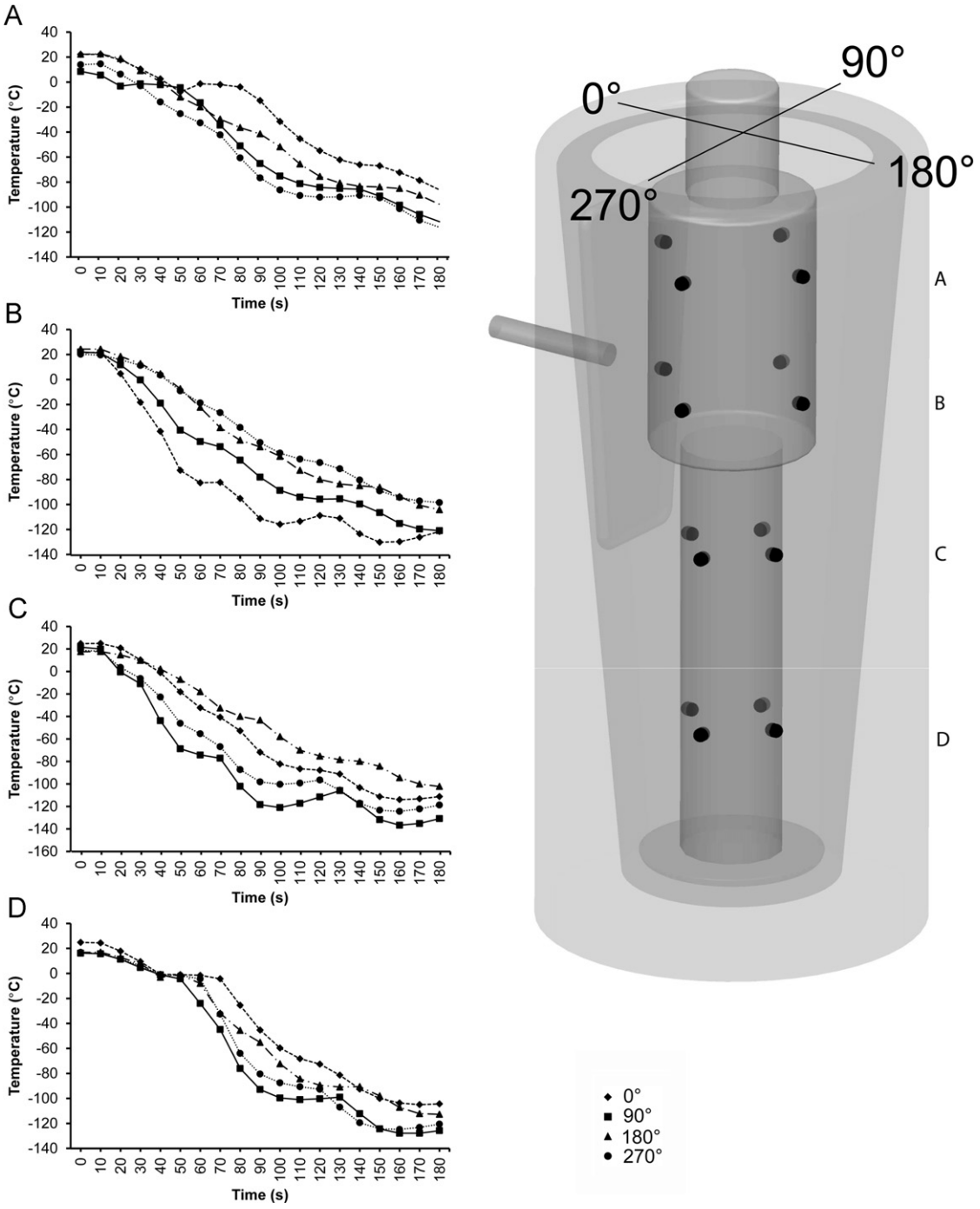

Fig. 5. Profiles of the temperature with a manikin measured at the height of the chest (A), trunk (B), thigh (C), and shank (D).

found to be lowest for thigh and shank, which indicates different temperature distribution when comparing cryo-cabin and cryo-chamber. Differences in temperature distribution are probably due to different number of nozzles and position of the nozzles in cryo-chamber. We can speculate that temperature is also more constant in cryo-chamber due to bigger volume of cold air and higher number of nozzles that inject liquid nitrogen.

We showed that actual temperature in the cryo-cabin is substantially different compared to the one reported by the manufacturer. This is important to draw conclusions regarding the temperature needed. Manufacturers should pay attention on temperature sensors placement for displaying the temperature inside the cabin. This would be particularly important for clinical use when adjusting the temperature for specific therapeutic purposes such as recovery after strenuous exercise (Banfi et al., 2010). Another important aspect that cryo-cabin manufacturers should consider is the reduction of temperature fluctuations and ensuring better temperature stability, as this could affect potential therapeutic outcome.

Further research on WBC in a cryo-cabin should concentrate on skin temperature measurements during the therapy in order to compare it against other cryogenic modalities. The thermal response after WBC in a cryo-cabin is similar to the response observed after WBC in a cryo-chamber. This could be of great practical value as cryo-cabins are less expensive and easier to use compared to cryo-chambers.

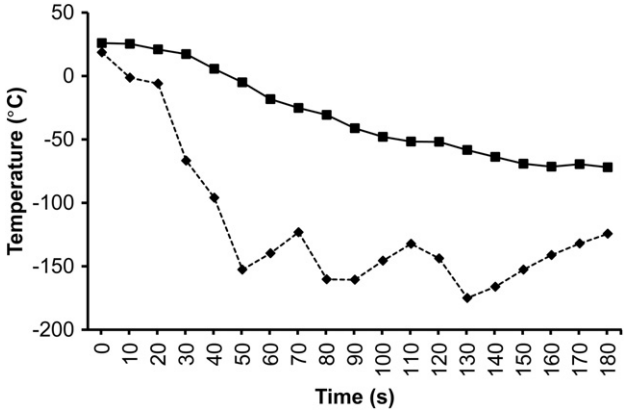

Fig. 6. Profiles of the temperature with an empty cryo-cabin at the position of the nozzle (dotted line) and centre of the cabin (solid line).

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