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Infrared thermography for assessing skin temperature differences between Partial Body Cryotherapy and Whole Body Cryotherapy devices at −140 °C

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ABSTRACT

Because of the scarcity of the literature on the comparative efficiency of Partial Body Cryotherapy versus Whole Body Cryotherapy, it appears that the decision to switch from the former to the latter is purely arbitrary and does not actually meet any scientifically established criterion. The motivation of this study is to draw up an objective observation of the differences between Partial Body Cryotherapy and Whole Body Cryotherapy treatments, based on the analysis of skin temperature distribution. Ten healthy subjects who engage in regular physical activity participated in the study (50% female; means ± S.D.: age 45.8 ± 5.5 years, height 168.7 ± 9,3 cm, weight 75.3 ± 13.1 kg, body fat percentage 19.3 ± 9,8). Sessions took place in a cryosauna and a cryochamber at identical temperature (−140 °C), duration of cryostimulation (3 min) and nature of the refrigerant used (liquid nitrogen vapor). It is shown that the skin temperature difference between Partial Body Cryotherapy and Whole Body Cryotherapy varies according to the vertical location of the body regions, increasingly from 15% on the lower areas of the body (no significant difference in skin temperature for legs $P = .171$) up to 53% for the upper areas (significant difference $P < 0.001$ for chest). These observations show the caution with which these two cryotherapy systems must be considered. The knowledge of the differences in cutaneous thermal response between these two systems should guide sports coaches and physicians in prescribing differentiated treatment protocols in order to achieve comparable skin temperature effects and consequently to efficiently cool tissues in the same way.

1. Introduction

Cryotherapy in cryosaunas or cryochambers is the therapeutic application of extremely cold dry air, usually between −140 °C and −110 °C with proven virtues on a number of pathologies such as pain [1] and inflammation stemming from sports injuries and muscular recovery [2–7], fibromyalgia [8,9], rheumatoid arthritis [10], multiple sclerosis [11], sleep [12] and depressive disorders [13], or skin diseases like psoriasis and dermatitis [14].

In recent years, there has been an ever-increasing development of structures offering Whole (WBC) and/or Partial (PBC) Body Cryotherapy [15] as a complementary therapy for the treatment of sport-related injuries and muscular recovery or medical pathologies. Because of the scarcity of the literature on the comparative efficiency of PBC versus WBC, it appears that the decision to switch from the former to the latter is purely arbitrary and does not meet any scientifically established criterion. To the best of our knowledge, the article by Hausswirth et al. [16] is the only study that compares WBC and PBC based on thermal, physiological and subjective variables. Conclusions of this study showed that WBC chambers provide noticeably higher cooling, greater autonomic response, higher cellular activation, and more uniform skin temperatures, making them significantly more effective than PBC in open-faced cryo saunas. Regrettably however, the conditions used in this study were very different: dry air at −110 °C for WBC versus liquid nitrogen vapor at −160 °C for PBC. In doing so, the conclusions of this unique comparative study between PBC and WBC seem not to be perfectly reliable, due to a possible bias.

The motivation of this study is not to take a stand for or against one of these PBC and WBC approaches, but to draw up an objective observation of the differences they induce in the body thermal stress response, analyzed from the perspective of skin temperature distribution. This makes sense when the comparison is achieved under similar conditions of protocol application, whether selected temperatures, duration of sessions or nature of the refrigerant (nitrogen in the present

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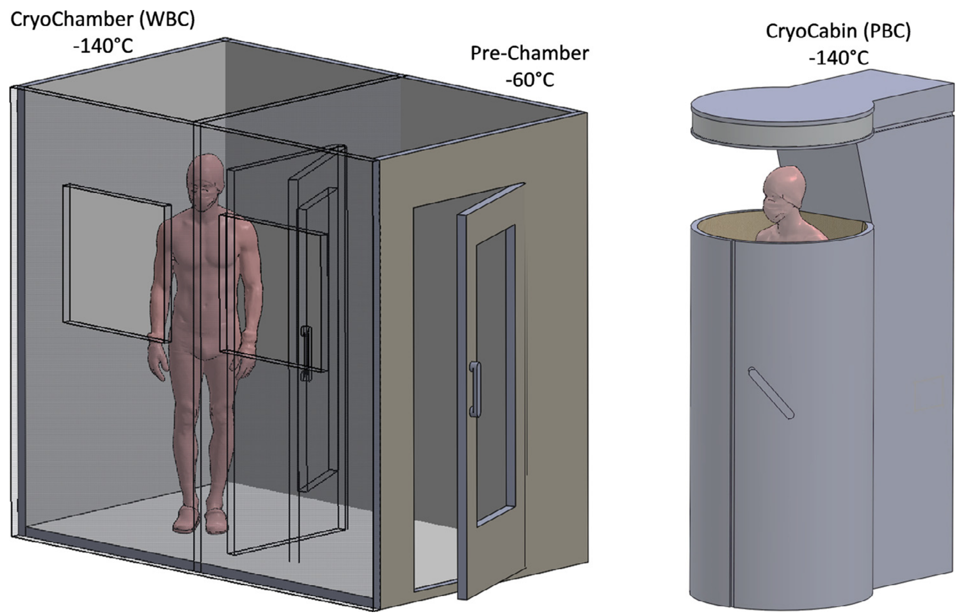

Fig. 1. Schematic view of Partial Body Cryotherapy (PBC) and Whole Body Cryotherapy (WBC) devices.

case). To the authors' knowledge, the present study is the first one to compare, in the same conditions, the two most widely used large field-size cryotherapy procedures nowadays.

2. Material and method

A broad range of cryotherapy and cold therapy devices, instruments, and applications are available today, allowing cold treatment from a small localized scale to a large field-size that encompasses the entire patient body. The two most commonly used types of large-scale cryotherapy equipment are the Whole Body Cryotherapy acting like a cryochamber, and the Partial Body Cryotherapy (i.e. cryocabin), as seen in Fig. 1. The main difference between a cryosauna and a cryochamber is that a cryosauna maintains the participant's head outside the cryo machine during the session. The cryo-user is exposed to nitrogen vapor from only the neck down, while a cryotherapy chamber acts like a walk-in freezer. It consists in a room that exposes the entire body to cold temperatures, generally in the range −140 °C to −110 °C.

Ten healthy subjects who engage in regular physical activity participated in the study (50% female; means ± S.D.: age 45.8 ± 5.5 years, height 168.7 ± 9,3 cm, weight 75.3 ± 13.1 kg, body fat percentage 19.3 ± 9,8). The pre-protocol of the study was built in accordance with the guidelines of the Declaration of Helsinki with respect to ethics and informed consent. Each participant received both types of cryostimulation (Cryogenic chamber and open-faced sauna; JUKA Poland) in a randomized order. Subjects were suitably protected from cold [17] to prevent adverse effects of low temperatures, using protective clothing composed of cotton socks, gloves, woolen hat to cover their ears and a disposable mask to cover their mouth. Setpoint temperature (−140 °C), duration of cryostimulation (3 min) and nature of the refrigerant used (liquid nitrogen vapor) were identical in both PBC and WBC conditions. The two experimental sessions (PBC and WBC) were conducted 24 h apart. This waiting time between two sessions is the one most used in cryotherapy protocols for non-specific treatment periods. All subjects were familiar with these cryotherapy procedures and had no medical contraindications to their practice. Before each operation, a check of their internal body temperature, blood pressure and heart rate has been conducted by a health professional to ensure they were in good health.

Skin temperature was recorded using a FLIR® Thermal SC620 Imaging Camera (FLIR Systems®, Wilsonville, OR) before and immediately after the cryo-session.

3. Results

Despite extreme cold superficial application, deep tissues are ordinary the target tissues of cryotherapy applications in numerous injuries. A strong relationship exists between skin and intramuscular temperatures [18]. It is the reason why skin temperature mapping over body surface provides useful information in many research and clinical applications [19]. In the present study, skin temperature has been considered as the relevant parameter on which the comparison between the two large field-size cryotherapy devices was conducted. Considered as an efficient, trustworthy and secure method in order to monitor skin temperature during cryotherapy [20], infrared thermography has been used to access the thermal mapping.

Fig. 2 illustrates as an example, an anterior and posterior image of the same female subject using infrared thermography, immediately after PBC and WBC application at −140 °C (duration 3 min). Healthy humans have a high degree thermal symmetry in the same regions in contralateral parts of the body. As seen in Fig. 2 (see the legs of the subject), slight, very localized thermal asymmetries can sometimes be observed, which may be due to localized vascularization anomalies or to a bad position of the subject within the devices. Biases on final results are minimized because, on the one hand, temperatures are averaged for each subject over large areas and, on the other hand, they are also statistically averaged over all subjects in the study. At first glance, a significant difference in skin temperature response to cold exposure between the two cold technologies appears, especially on the upper body. A similar trend was observed in all subjects of the study. The main reason lies in the design of the cryosauna tank (PBC device), where the operator raises the user platform such that, for safety reasons, the head is located above cold nitrogen vapors to allow room air breathing. What differs from WBC is that the warmest dorsal area of the back begins at the bottom of the spine, and spreads in a trapezoidal shape towards the shoulders in the PBC situation.

Quantitatively, thermal imaging was analyzed according to the regions of interest, namely chest, upper back, arms, belly, lower back and legs. The reference skin temperature corresponds to the rest temperature, taken before the cryotherapy sessions. Fig. 3 represents the measured relative temperature before and immediately post cryotherapy treatment for different body regions of interest. It is clear that under

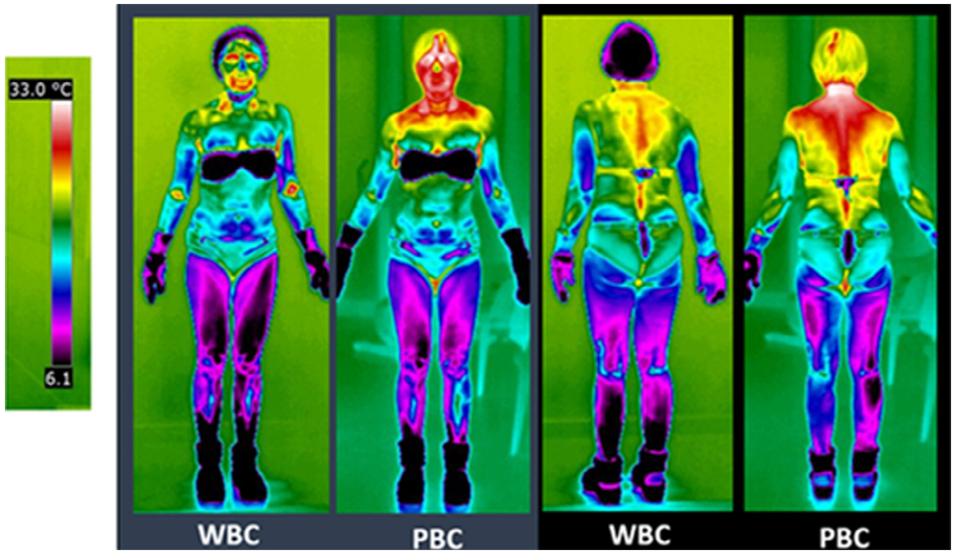

Fig. 2. Examples of thermal imaging in female subject immediately post-treatment for Partial Body Cryotherapy (PBC) and Whole Body Cryotherapy (WBC) at −140 °C.

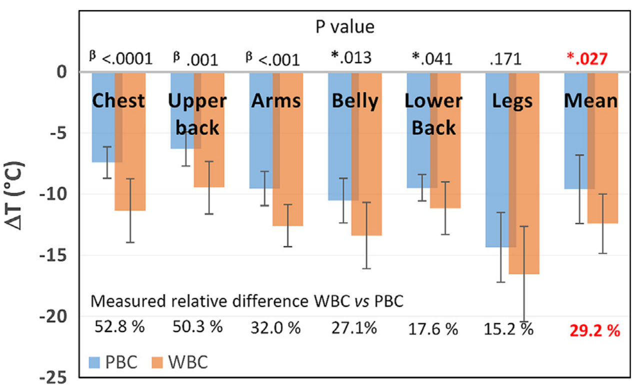

Fig. 3. Skin thermal gradient ΔT between post-treatment and rest states in body regions of interest after 3 min PBC and WBC at −140 °C (* *indicates a significant skin temperature difference between PBC and WBC* $P \leq 0.05$. $^{\beta}$ *indicates a significant skin temperature difference between PBC and WBC* $P \leq 0.001$).

identical conditions of protocol application, the human body cools down much more in its periphery in WBC than in PBC, the average difference being around 29%. As seen in Fig. 3, looking more closely shows that this difference varies according to the vertical location of the body regions, increasingly from 15% on the lower areas of the body (no significant difference in skin temperature for legs $P = .171$) up to 53% for the upper areas (significant difference $P < 0.001$ for chest). These large deviations reflect the presence of a strong thermal stratification within the fluid surrounding the body, especially in confined PBC environment.

Two main technological reasons can explain the differences observed between PBC and WBC. The first one is that in PBC the upper regions of the body exchange differently heat with the environment (room temperature) due to their proximity to the opening of the cryocabin while the lower regions of the body are embedded in a very cold atmosphere. The colder the environment around the subject, the greater the heat exchange and heat loss between the body's regions and this environment, resulting in a reduction in skin temperature. The second reason is linked to the strong confined environment of the cryocabin whose inner fluid is more stirred and more sensitive to the vertical thermal gradient (room temperature at the top and extreme cold one at the bottom). As mixing takes place inside the cabin, density of the nitrogen mixture decreases (nitrogen is about 260% heavier than air at −140 °C). Therefore, high density mixture stagnates at the bottom of the cabin, while lower density layers tend to wind up and consequently the fluid temperatures inside the cryocabin are more heterogeneous than devices used in WBC.

One will also notice, from a physiological point of view, that whatever cryotherapy device is used, it is the legs that are most sensitive to extreme cold. This shows that, intrinsically, the body regions can have a different response to cold. One hypothesis may be that the phenomenon of vasoconstriction (natural protection of the body to limit heat loss) is more pronounced on this peripheral organ, or that the percentage of adipose tissue in relation to the volume of this organ is greater. The question remains open and would require future studies.

4. Conclusion

These observations show the caution with which these two cryotherapy systems must be considered by athletes, trainers and sport medicine physicians while they could legitimately believe that they lead to the same effects (similar conditions of setpoint temperature, duration and cooling technology). Without prior knowledge of the differences between these two approaches, the effects they might think to be beneficial may be zero or even deleterious on the cold treatment of some pathologies (e.g. articular in direct contact with the skin or more deeply in subcutaneous tissues) linked to sport or for muscular recovery, as the skin temperatures differ so much. For clinical applications the way to efficiently cool injured tissues, in order to reach for example analgesic threshold, will highly depend on the cryotherapy device, especially if the area concerned is in the upper part of the body.

The present findings show that more experimental approaches are needed to replace the current empiricism of the cryotherapy protocols used [21], when the choice can be made between WBC and PBC. Moreover, if the objective of this study was to identify a trend based on a statistical analysis that did not take into account the sex of the participants, then more detailed studies, especially on this question of sexual dimorphism, would be needed for the definition of appropriate protocols for males and females.

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Conflict of interest

We affirm that we have no financial affiliation (including research funding) or involvement with any commercial organisation that has a direct financial interest in any matter included in this manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.infrared.2018.07.025.

References

[1] A.A. Algafly, K.P. George, The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance, Br. J. Sports Med. 38 (1) (2007) 365–369.

[2] G. Banfi, G. Melegati, A. Barassi, G. Dogliotti, G. Melzi d'Eril, B. Dugué, M.M. Corsi, Effects of whole-body cryotherapy on serum mediators of inflammation and serum muscle enzymes in athletes, J. Therm. Biol. 34 (2009) 55–59.

[3] C. Hausswirth, J. Louis, F. Bieuzen, H. Pournot, J. Fournier, J.R. Filliard, J. Brisswalter, Effects of whole-body cryotherapy vs. far-infrared vs. passive modalities on recovery from exercise-induced muscle damage in highly-trained runners, PLoS ONE 6 (2011) e27749.

[4] E. Ziemann, R.A. Olek, S. Kujach, T. Grzywacz, J. Antosiewicz, T. Garsztka, R. Laskowski, Five-day whole-body cryostimulation, blood inflammatory markers, and performance in high-ranking professional tennis players, J. Athl. Train. 2012 (47) (2012) 664–672.

[5] A.E. Abaïdia, J. Lamblin, B. Delecroix, C. Leduc, A. McCall, M. Nédélec, B. Dawson, G. Baquet, G. Dupont, Recovery from exercise-induced muscle damage: cold-water immersion versus whole-body cryotherapy, Int. J. Sports Physiol. Perform. 12 (3) (2017) 402–409.

[6] D.H. Serravite, A. Perry, K.A. Jacobs, J.A. Adams, K. Harriell, J.F. Signorile, Effect of whole-body periodic acceleration on exercise-induced muscle damage after eccentric exercise, Int. J. Sports Physiol. Perform. 9 (6) (2014) 985–992.

[7] A.R. Jajtner, J.R. Hoffman, A.M. Gonzalez, P.R. Worts, M.S. Fragala, J.R. Stout, Comparison of the effects of electrical stimulation and cold-water immersion on muscle soreness after resistance exercise, J. Sport Rehabil. 24 (2) (2015) 99–108.

[8] M. Vitenet, F. Tubez, A. Marreiro, G. Polidori, R. Taiar, F. Legrand, F.C. Boyer, Effect of whole body cryotherapy interventions on health-related quality of life in fibromyalgia patients: a randomized controlled trial, Complement Ther. Med. 36 (2018) 6–8.

[9] L. Bettoni, F.G. Bonomi, V. Zani, et al., Effects of 15 consecutive cryotherapy sessions on the clinical output of fibromyalgic patients, Clin. Rheumatol. 32 (2013) 1337–1345.

[10] K. Księżopolska-Orłowska, A. Pacholec, A. Jędryka-Góral, et al., Complex rehabilitation and the clinical condition of working rheumatoid arthritis patients: does cryotherapy always overtop traditional rehabilitation? Disabil. Rehabil. 38 (11) (2016) 1034–1040.

[11] E. Miller, M. Mrowicka, K. Malinowska, J. Mrowicki, J. Saluk-Juszczak, J. Kedziora, The effects of whole-body cryotherapy on oxidative stress in multiple sclerosis patients, J. Therm. Biol. 35 (8) (2010) 406–410.

[12] R. Bouzigon, G. Ravier, B. Dugue, The use of whole-body cryostimulation to improve the quality of sleep in athletes during high level standard competitions, Br. J. Sports Med. 48 (7) (2014) 572.

[13] J. Rymaszewska, D. Ramsey, S. Chladzinska-Kiejna, Whole-body cryotherapy as adjunct treatment of depressive and anxiety disorders, Arch. Immunol. Ther. Exp. (Warsz) 56 (1) (2008) 63–68.

[14] T. Klimenko, S. Ahvenainen, S.L. Karvonen, Whole-body cryotherapy in atopic dermatitis, Arch. Dermatol. 144 (6) (2008) 806–808.

[15] R. Bouzigon, F. Grappe, G. Ravier, B. Dugue, Whole- and partial-body cryostimulation/cryotherapy: current technologies and practical application, J. Therm. Biol. 61 (2016) 67–81.

[16] C. Hausswirth, K. Schaal, Y. Le Meur, F. Bieuzen, J.R. Filliard, M. Volondat, J. Louis, Parasympathetic activity and blood catecholamine responses following a single partial-body cryostimulation and a whole-body cryostimulation, PLoS One 8 (8) (2013) e72658.

[17] J.T. Costello, K. Culligan, J. Selfe, A.E. Donnelly, Muscle, skin and core temperature after −110 °C cold air and 8°C water treatment, PLoS One 7 (11) (2012) e48190.

[18] N.J. Hardaker, A.D. Moss, J. Richards, S. Jarvis, I. McEwan, J. Selfe, Relationship between intramuscular temperature and skin surface temperature as measured by thermal imaging camera, Thermol. Int. 17 (2) (2007) 45–50.

[19] B.B. Lahiri, S. Bagavathiappan, T. Jayakumar, J. Philip, Medical applications of infrared thermography: a review, Infrared Phys. Technol. 55 (2012) 221–235.

[20] E. Matos, E. Borda Neves, M. Norte, C. Rosa, V.M. Reis, J. Vilaça-Alves, The use of thermal imaging to monitoring skin temperature during cryotherapy: a systematic review, Infrared Phys. Technol. 73 (2015) 194–203.

[21] C.M. Bleakley, J.T. Hopkins, Is it possible to achieve optimal levels of tissue cooling in cryotherapy? Phys. Ther. Rev. 15 (4) (2010) 344–350.