ORIGINAL ARTICLE

Hyperbaric Gaseous Cryotherapy: Effects on Skin Temperature and Systemic Vasoconstriction

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ABSTRACT. Mourot L, Cluzeau C, Regnard J. Hyperbaric gaseous cryotherapy: effects on skin temperature and systemic vasoconstriction. Arch Phys Med Rehabil 2007;88:1339-43.

Objective: To compare skin-surface cooling caused by the application of an ice bag (15min) and the projection of carbon dioxide microcristals (2min) under high pressure (75 bar) and low temperature (−78°C), a modality called hyperbaric gaseous cryotherapy.

Design: Randomized controlled trial with repeated measure.

Setting: Laboratory experiment.

Participants: Twelve healthy male subjects (mean ± standard deviation, 22.9±1.8y).

Interventions: Ice bag and hyperbaric gaseous cryotherapy were randomly applied on the skin of the nondominant hand.

Main Outcome Measure: Skin temperature of the cooled (dorsal and palmar sides) and contralateral (dorsal side) hands were continuously measured with thermistor surface-contact probes before, during, and after (30min) cooling.

Results: Hyperbaric gaseous cryotherapy projection induced a large decrease ($P<.05$) of the dorsal skin temperature of the cooled hand (from 32.5°±0.5°C to 7.3°±0.8°C) and a significant decrease of the skin temperature of the palmar side and of the contralateral hand. The skin temperature of the dorsal side of the cooled hand was decreased with an ice bag (from 32.5°±0.6°C to 13.9°±0.7°C, $P<.05$). However, the lowest temperature was significantly higher than during hyperbaric gaseous cryotherapy, and no significant changes in the other skin temperatures were observed. Rewarming was equal after the 2 modalities, highlighting a more rapid increase of the skin temperature after hyperbaric gaseous cryotherapy.

Conclusions: Hyperbaric gaseous cryotherapy projection decreased the skin temperature of the cooled and contralateral hand, suggesting a systemic skin vasoconstriction response. On the other hand, the vascular responses triggered by ice pack cooling appeared limited and localized to the cooled area.

Key Words: Cold; Cryotherapy; Dry ice; Ice; Nervous system diseases, sympathetic; Rehabilitation.

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Supported by the French Ministry of National Education, Research and Technology (grant no. UPRES EA3920).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

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0003-9993/07/8810-00052$32.00/0
doi:10.1016/j.apmr.2007.06.771

THE TERM *CRYOTHERAPY* refers to the achievement of a therapeutic objective through the lowering of the tissue temperature by the withdrawal of heat from the body.[1] A critical level of tissue cooling is required for specific effects.[2-6] Ice massage,[7] mixture of water and alcohol,[8] or nitrogen cold air[9] are efficient cooling techniques, but among the various cryotherapy modalities available for use both in clinical and on-field settings, ice or a gel bag or pack are probably the most frequently used. A series of studies[10,11] reported that critical temperatures are not typically achieved with these modalities, thus limiting the therapeutic effect.

Despite a general consensus regarding the physiologic effects of cryotherapy, there are no clear guidelines on the optimum application technique for acute cryotherapy. Thus, there is no strong evidence to justify the use of one cryotherapy modality over the others.[12] It is generally believed that greater cooling leads to more profound metabolic suppression, suggesting that cryotherapy modalities that produce lower temperatures are more efficacious.[7,10,11,13-15] Similarly, it is generally assumed that cryotherapy techniques that provide more rapid cooling of tissues may offer some advantage over slower cooling techniques. With traditional ice and a cold gel pack, achievement of temperatures low enough to produce local analgesia[2] by conduction are usually obtained after 5 to 10 minutes.[8,14]

With the intention of drastically shortening cooling time, the Cryonic Society developed a cryotherapy modality that lowers the tissue temperature by convection. A reduced skin temperature is achieved through sublimation on the skin of carbon dioxide microcristals under high pressure (75 bar) and low temperature (−78°C). The aim of this study was to directly compare the skin-surface temperature during and after the application of a commonly used latex ice bag and of hyperbaric gaseous cryotherapy by carbon dioxide application.

METHODS

Experimental Design

We used a repeated-measures design to compare the skin-surface temperature during the application of the 2 cryotherapy modalities. Time and cryotherapy modalities were the independent variables, whereas skin-surface temperature was the dependent variable. Subjects were tested with 2 cryotherapy modalities: an ice bag and hyperbaric gaseous cryotherapy on 2 occasions with at least a 24-hour interval between occasions. To control the order effects, subjects were randomly allocated. Subjects were also asked to refrain from consuming alcohol, caffeine, or food for 3 hours and from any vigorous activities for 24 hours before testing to help stabilize extremity blood flow. None of the subjects in this study reported negative reactions to the cold treatments.

Participants

Twelve male subjects (mean ± standard deviation [SD], 22.9±1.8y; height, 178.3±2.0cm; weight, 70.6±2.2kg) from a university student population voluntarily participated in this study. Their medical history and a medical examination were used to exclude subjects with a history of smoking, cardiovascular or peripheral vascular disease, diabetes, neurologic pathologies, recent trauma or injury to the hand, presence of any sores or open wounds on the hand, local hot or cold insensitivity, and very fair skin. We chose these criteria to avoid any harm or discomfort to the subjects; they were in keeping with previous studies.[10,11] Subjects were normotensive, and none was taking medication. They were informed of the organization and details of the study, which was approved by our local ethics committee, and they were reminded of their right to withdraw at any stage. All patients provided written informed consent according to the Declaration of Helsinki. None of the 12 prospects was excluded from the study.

Experimental Procedures

A sole investigator made all data measurements to reduce measurement variability. Subjects were in the supine position on a treatment table during the entire test. A control period was imposed for a minimum of 20 minutes before starting temperature measurements in an effort to allow body temperatures to stabilize and to control for temperature fluctuations resulting from any pre-experiment physical activity.

The dorsal face of the nondominant hand was cooled in each therapy. The ice bag was prepared from ice chips and had a diameter of 25cm. Air was evacuated from the bag to allow the bag to better form to the hand surface. Care was taken to cool only the hand from the distal part of the wrist to the extremity of the fingers. With hyperbaric gaseous cryotherapy, cold was applied on the same area by sweeping motions. Because of the ability of hyperbaric gaseous cryotherapy to rapidly withdraw heat, application time differed between modalities; cooling lasted 15 minutes with the ice bag[7,10] and only 2 minutes with hyperbaric gaseous cryotherapy (manufacturer's recommendations).

Skin temperatures were recorded at the following sites: (1) the center point of the cooled area (middle of the third metacarpus), (2) the opposite side (palmar side) of the same hand, and (3) the middle of the third metacarpus of the dorsal contralateral hand. Skin temperatures were recorded every 30 seconds during the first 2 minutes of application and then every 2 minutes until the end of application of the modality (ice bag only); every 30 seconds during the first 3 minutes of rewarming and then every minute from 3 to 6 minutes of rewarming; and, finally, every 2 minutes during the remaining 30 minutes of rewarming. Subjects were permitted to leave when sensation in the tested area returned to normal. No subjects experienced any adverse reactions to the experimental protocol.

Materials

Skin-surface temperatures were measured by means of thermistor surface-contact probes[a] fixed on the skin with thin, air-permeable, adhesive surgical tape. By using uniform amounts of tape covering an equal area for each treatment, we controlled the potential insulating effect of the tape, and it was assumed that a uniform effect would be produced across all treatments. Therefore, it would not interfere with our ability to discriminate among treatments. Room temperature was maintained at a mean of 25°±1°C for all testing sessions.[b]

Ice bag and hyperbaric gaseous cryotherapy by carbon dioxide were the modalities used in this study. The ice bag[c] was a 25-cm diameter latex bag filled with chipped ice (0°–1°C). In this case, air was evacuated from the latex bag in an attempt to improve conforming of the bag to the body surface. The amount of ice was 400g. For hyperbaric gaseous cryotherapy, we used the Cryo+ apparatus.[d] This device throws up carbon dioxide microcristals under low temperature (−78°C) and high pressure (50 bars at the outlet pipes, 2 bars on the skin). Medical carbon dioxide, in liquid form, is stored in bottles with a valve and a dip tube. Cold was applied on the dry skin with sweeping motions by using a spray gun linked to the carbon dioxide bottle. The pipe was maintained at a distance of 7 to 10cm of the skin surface. With this technique, it was possible to see the action of the cold by observation of the microcristals on the skin. Skin-temperature reduction is controlled by an infrared thermometer incorporated into the gun and application time of the gas is displayed on a screen.

Statistical Analysis

Standard statistical methods were used for the calculation of mean ± SD. Statistical comparisons of skin surface temperature were made by using a repeated-measures 2-way analysis of variance. A Student-Newman-Keuls test was used post hoc when interactions were significant. The statistical significance was established at the P less than .05 level. All analyses were performed by using SigmaStat.[e]

RESULTS

The mean skin-surface temperatures for the 2 modalities at the end of the baseline periods were 32.5°±0.6°C (ice bag) and 32.5°±0.5°C (hyperbaric gaseous cryotherapy) for the dorsal cooled hand, 33.7°±0.7°C (ice bag) and 33.5°±0.6°C (hyperbaric gaseous cryotherapy) for the palmar cooled hand, and 31.0°±0.7°C (ice bag) and 30.8°±0.6°C (hyperbaric gaseous cryotherapy) for the dorsal contralateral hand (fig 1). At base-

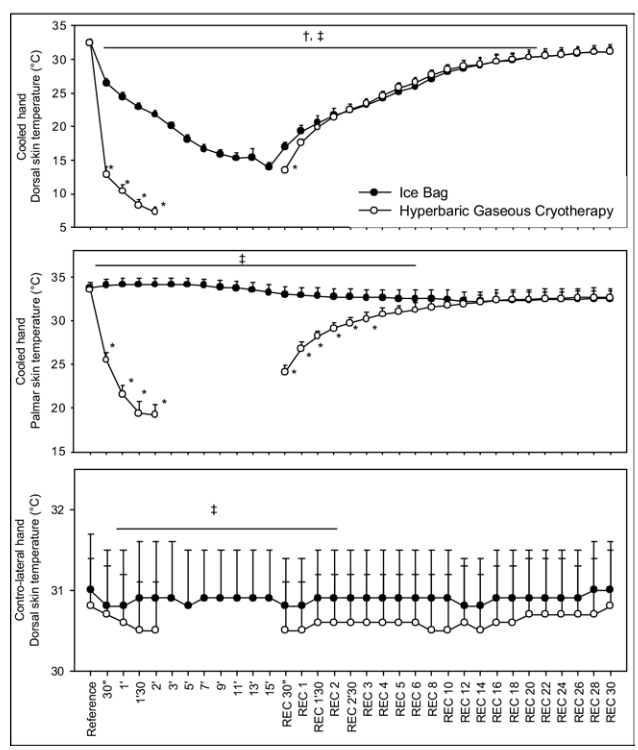

Fig 1. Skin-surface temperatures of the cooled and of the contralateral hand during and after 15 minutes of ice bag application and 2 minutes of hyperbaric gaseous cryotherapy. Abbreviation: REC, recovery. *Significant difference between ice bag and hyperbaric gaseous cryotherapy; †significant difference from the reference values (ice bag); ‡significant difference from the reference values (hyperbaric gaseous cryotherapy) at the P<.05 level.

line, no significant differences were observed between ice bag and hyperbaric gaseous cryotherapy.

Ice bag and hyperbaric gaseous cryotherapy decreased the temperature of the dorsal aspect of the cooled hand significantly throughout the cold application (see fig 1). However, the rate of skin temperature decrease and the drop in skin temperature was dependent of the technique used. With the ice bag, the skin temperature decreased to 26.5°±0.7°C (−6°C) in the first 30 seconds ($P<.05$ vs baseline) and then more slowly to reach 21.8°±0.6°C at 2 minutes (−11°C; range, −5.0° to −8.1°C) and finally 13.9°±0.7°C (−19°C; range, −15.6° to −20.8°C) at the end of the 15-minute application. With hyperbaric gaseous cryotherapy, the skin temperature decreased to 12.8°±1.2°C (−20°C; range, −14.4°C to −25.8°C) within 30 seconds ($P<.05$ vs baseline and ice bag) and then more progressively to reach 7.3°±0.8°C (−25°C; range,−18.4°C to −30.0°C) at the end of the 2-minute application. The overall reduction in the skin temperature was larger with hyperbaric gaseous cryotherapy compared with an ice bag ($P<.05$). After removal of the application, rewarming was faster after hyperbaric gaseous cryotherapy, particularly at the very beginning of recovery. Thirty seconds after the removal of the ice bag, the skin temperature was 16.9°±0.8°C (+3°C; range, 1.9°−4.0°C), whereas it was 13.5°±0.6°C (+6°C; range, 3.8°−9.1°C) for hyperbaric gaseous cryotherapy ($P<.05$ vs ice bag). After 1 minute of rewarming, no significant difference in skin temperature was observed between ice bag and hyperbaric gaseous cryotherapy. After 20 minutes of recovery, neither cryotherapy modalities differed significantly from baseline values. Like the temperature reductions on the dorsal side of the cooled hand, the palmar skin temperature changes were also dependent of the cooling technique used (see fig 1). A trend for an increase in the skin temperature was observed during the first 6 minutes of ice bag application (up to 34.0°±0.7°C; +0.3°C; range, −0.4°C to +1.2°C; P=not significant) before decreasing to reach 33.2°±0.9°C at the end of the cooling period. At this time, no significant difference with the baseline skin temperature was observed. During hyperbaric gaseous cryotherapy, the palmar skin temperature decreased ($P<.05$) to reach 19.2°±1.2°C (−14°C; range, −6.5°C to −21.5°C) at the end of the 2-minute application.

No significant change in the dorsal skin temperature of the contralateral hand was observed during ice bag application (see fig 1). However, a significant decrease was observed with hyperbaric gaseous cryotherapy; the temperature dropped to 30.5°±0.6°C (−0.3°C; range, −0.1°C to −0.7°C) at the end of the cooling period. The skin temperature remained significantly lower than that of baseline during the 2 first minutes after the end of cold application.

DISCUSSION

This study investigated the effect of application of a traditional latex ice bag and a hyperbaric gaseous cryotherapy device on the surface skin temperature of the human hand. The results suggest that greater reductions in skin temperatures and a greater rate of heat removal are achieved with hyperbaric gaseous cryotherapy compared with an ice bag.

Cold modalities work by absorbing heat from their immediate environment, particularly from the tissues being treated. The transfer of heat and the capacity of the cold modality to absorb this heat determines the modality's effectiveness and depend on several factors, such as the relative masses of the bodies, the size of the contact area, the difference in starting temperatures, and the heat capacity or specific heat of each material.[16] In the present study, the only difference between treatments was caused by differences in the specific heat of the modalities used and their ability to absorb heat. Hyperbaric gaseous cryotherapy is based on a source of liquid carbon dioxide which converts, when applied on the skin, to a white solid phase (dry ice) through a process called deposition. Then, at atmospheric pressure, dry ice gradually sublimates to carbon dioxide gas (sublimation). The amount of heat absorption through this process is greater compared with the heat absorption operated through convection with the ice bag, explaining the greater and more rapid decrease in skin temperature. Also, condensation occurred at the surface of the ice bag during the 15-minute application, and, thus, a small amount of cold water was in contact with the skin of the subject's hand. On the other hand, convection during hyperbaric gaseous cryotherapy involved dry gas. One potential advantage of such a difference is that pain is lessened during a dry cold than during a wet cold stimulation.[17] However, pain sensation was not evaluated in the present study.

Comparing the present results with other research findings is difficult because of the different protocol used (time and site of cold application).[12] However, the relative clinical merits of each modality can be established by reviewing the tissue temperatures achieved in relation to target tissue temperatures. Based on previous research, a skin temperature below 13.6°C is required to induced localized analgesia,[2] a reduction of nerve conduction velocity is observed at a temperature of 12.5°C,[3-5] and tissue temperatures between 10° and 11°C reduced metabolic enzyme activity.[3,6] It is of note that large variation exists in individual responses to cold. Clinically, this variation is a concern, given the importance of the actual skin temperature that must be achieved to induce the different physiologic effects. It is, therefore, worth questioning whether generic application protocols and times will always ensure clinically effective tissue cooling. The ice bag did not achieve a mean skin temperature below 13.9°C. This suggests that the ice bag would not be suitable to achieve these particular clinically relevant tissue temperatures when applied to the hand in this manner. In the present study, the skin temperature on the cooled surface was lower than 13.6°C in 6 subjects and lower than 12.5° and 11°C in only 2 of 12 subjects after 15 minutes of ice bag application. The interindividual variation was large in this case because skin temperature ranged from 9.7° to 17.7°C. Because there was a continual decrease in the mean surface temperature for the duration of ice pack application, clinically relevant temperatures may have been reached with a longer application time. However, a prolonged application at low temperatures should be avoided because this may cause serious side effects, such as frostbite and nerve injuries.[18,19] On the other hand, hyperbaric gaseous cryotherapy led to a skin temperature below 11°C in every subject at the end of the 2-minute application. This suggests that hyperbaric gaseous cryotherapy has adequate heat abstraction capabilities to justify its use for achieving localized analgesia, reduced nerve-conduction velocity, and cell metabolism. It is not known if very rapid cooling could also have side effects, but, because the hyperbaric gaseous cryotherapy has a great capacity to absorb heat, this modality may also cause injuries if mismanaged.

Twenty minutes after the removal of the cryotherapy modalities, the mean skin-surface temperature was not significantly different from baseline. It is interesting to note that the 2 cryotherapy modalities achieved a similar level of mean skin surface temperature during the rewarming despite the fact that the mean skin surface temperatures before removal differed. Because heat always transfers from the warmer environment into the cooler environment,[14,20] the similar level of the mean skin-surface temperature at the end of the rewarming may imply that the cooling effects of the topical cryotherapy application in this study are short-lived. The important changes in the skin temperature observed with hyperbaric gaseous cryotherapy may be of interest based on the assumption that immediate cryotherapy application will be more beneficial than delayed application because the sooner the metabolic rate is reduced after injury, the less the secondary damage.[14]

In the present study, we chose to cool the hand instead of the thigh, as usually performed in studies comparing different cryotherapy modalities.[8,14] This was done because subjects' skinfold thickness is thin at this site and the vascular bed is highly developed, therefore magnifying the thermal alterations. Also, changes in hand skin temperature could be used as an indicator of the sympathetic activity,[21-23] giving information on the vascular autonomic control during cooling. In the present study, a significant decrease in the skin temperature of the palmar face of the cooled hand and of the contralateral hand was found with hyperbaric gaseous cryotherapy and not with ice bag cooling, suggesting that the cutaneous vasoconstriction triggered by hyperbaric gaseous cryotherapy was systemic, whereas that triggered by the ice bag was localized only to the cooled area. This should be noted because evidence has shown that sympathetic activity modulates inflammation and the release of cytokines[24] and that involvement of the autonomic nervous system is important in the treatment of inflammation.[25]

Study Limitations

Several methodologic restrictions limit the generalization of our findings.

The subjects of the present study were a selected group of young healthy men, which enhances internal validity and data purity. However, they are not representative of the population as a whole,[26-28] restricting the external validity of this study. Likewise, injured subjects may not respond in the same fashion because of their inflammatory status and higher temperature at the wounded site. During cold application, there is a direct relationship between adipose thickness,[29] vascularity of the tissue, local blood flow,[30] and both the required cooling time and the temperature change, suggesting that adjustments to cryotherapy duration may be necessary to produce similar temperature changes at different body segments. Hyperbaric gaseous cryotherapy was compared with the use of an ice pack because it is likely the most frequently used modality in clinics and on the field. However, more rapid and deeper tissue cooling compared with an ice bag could be achieved with other cryotherapy modalities.[7-9] It is necessary to compare the efficacy of hyperbaric gaseous cryotherapy to these alternative modalities. Finally, in lieu of more direct measures, the clinical efficacy of cryotherapy is often assessed through skin-surface temperature measurements. It is assumed that skin-surface temperature declines in a fashion similar to that of intramuscular temperature during the course of cryotherapy application[7,14,20]; however, this may be incorrect.[31] Also, the duration of the intramuscular temperature reduction is dependent of the cooling modalities.[15,32]

CONCLUSIONS

Hyperbaric gaseous cryotherapy was superior to the ice bag in reducing skin temperature. This modality decreased the mean skin-surface temperature to levels required for therapeutic effects in all subjects studied, whereas the ice bag did not. Unlike the ice bag, hyperbaric gaseous cryotherapy triggered a systemic vasoconstriction. Confirmation of these results with a larger population is necessary, and the clinical benefits of hyperbaric gaseous cryotherapy need to be evaluated.

Acknowledgments: We thank Melanie I. Stuckey, MS, for her helpful comments during the preparation of this manuscript. We thank the Cryonic Society, which placed the Cryo+ apparatus at our disposal for the study.

References

1. Meeusen R, Lievens P. The use of cryotherapy in sports injuries. Sports Med 1986;3:398-414.
2. Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. Phys Ther 1975;55:11-9.
3. Knight KL. Effects of hypothermia on inflammation and swelling. J Athl Train 1976;11:7-10.
4. McMeeken J, Murrayn L, Cocks S. Effects of cooling with simulated ice on skin temperature and nerve conduction velocity. Aust J Phys 1984;30:111-4.
5. Denys EH. AAEM minimonograph #14: the influence of temperature in clinical neurophysiology. Muscle Nerve 1991;14:795-811.
6. Zachariassen KE. Hypothermia and cellular physiology. Arctic Med Res 1991;50(Suppl 6):13-7.
7. Andersen JC, Guion WK, Joyner AB, McMillan J, Zemke JE. Intramuscular temperature responses in the human leg to two forms of cryotherapy: ice massage and ice bag. J Orthop Sports Phys Ther 1998;27:301-7.
8. Kanlayanaphotporn R, Janwantanakul P. Comparison of skin surface temperature during the application of various cryotherapy modalities. Arch Phys Med Rehabil 2005;86:1411-5.
9. Oosterveld FG, Rasker JJ. Effects of local heat and cold treatment on surface and articular temperature of arthritic knees. Arthritis Rheum 1994;37:1578-82.
10. Belitsky RB, Odam SJ, Hubley-Kozey C. Evaluation of the effectiveness of wet ice, dry ice, and cryogenic packs in reducing skin temperature. Phys Ther 1987;67:1080-4.
11. Chesterton LS, Foster NE, Ross L. Skin temperature response to cryotherapy. Arch Phys Med Rehabil 2002;83:543-9.
12. Bleakley C, McDonough S, MacAuley D. The use of ice in the treatment of acute soft-tissue injury: a systematic review of randomized controlled trials. Am J Sports Med 2004;32:251-61.
13. Sapega AA, Heppenstall RB, Sokolow DP, et al. The bioenergetics of preservation of limbs before replantation. The rationale for intermediate hypothermia. J Bone Joint Surg Am 1988;70:1500-13.
14. Merrick MA, Jutte LS, Smith ME. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. J Athl Train 2003;38:28-33.
15. Myrer W, Meason G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. J Athl Train 1998;33:25-9.
16. Knight KL. Cryotherapy in sports injury management. Champaign: Human Kinetics; 1995.
17. Shibahara N, Matsuda H, Umeno K, Shimada Y, Itoh T, Terasawa K. The responses of skin blood flow, mean arterial pressure and R-R interval induced by cold stimulation with cold wind and ice water. J Auton Nerv Syst 1996;61:109-15.
18. de Cree C. Frostbite at the gym: it's not the ice but the temperature that matters! Br J Sports Med 1999;33:435-6.
19. Drez D, Faust DC, Evans JP. Cryotherapy and nerve palsy. Am J Sports Med 1981;9:256-7.
20. Enwemeka CS, Allen C, Avila P, Bina J, Konrade J, Munns S. Soft tissue thermodynamics before, during, and after cold pack therapy. Med Sci Sports Exerc 2002;34:45-50.
21. Frank SM, Raja SN. Reflex cutaneous vasoconstriction during cold pressor test is mediated through alpha-adrenoceptors. Clin Auton Res 1994;4:257-61.
22. Kistler A, Mariauzouls C, von Berlepsch K. Fingertip temperature as an indicator for sympathetic responses. Int J Psychophysiol 1998;29:35-41.

23. Wright CI, Kroner CI, Draijer R. Non-invasive methods and stimuli for evaluating the skin's microcirculation. J Pharmacol Toxicol Methods 2006;54:1-25.
24. Hasko G, Szabo C. Regulation of cytokine and chemokine production by transmitters and co-transmitters of the autonomic nervous system. Biochem Pharmacol 1998;56:1079-87.
25. Pavlov VA, Tracey KJ. The cholinergic anti-inflammatory pathway. Brain Behav Immun 2005;19:493-9.
26. Cankar K, Finderle Z. Gender differences in cutaneous vascular and autonomic nervous response to local cooling. Clin Auton Res 2003;13:214-20.
27. Kenney WL, Armstrong CG. Reflex peripheral vasoconstriction is diminished in older men. J Appl Physiol 1996;80:512-5.
28. Thompson CS, Holowatz LA, Kenney WL. Cutaneous vasoconstrictor responses to norepinephrine are attenuated in older humans. Am J Physiol Regul Integr Comp Physiol 2005;288:R1108-13.
29. Otte JW, Merrick MA, Ingersoll CD, Cordova ML. Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. Arch Phys Med Rehabil 2002;83:1501-5.
30. Bierman W, Friedlander M. The penetrative effect of cold. Arch Phys Ther 1940;21:585-91.
31. Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. Arch Phys Med Rehabil 2001;82:845-50.
32. Akgun K, Korpinar MA, Kalkan MT, Akarirmak U, Tuzun S, Tuzun F. Temperature changes in superficial and deep tissue layers with respect to time of cold gel pack application in dogs. Yonsei Med J 2004;45:711-8.

Suppliers

a. Thermistor surface contact probes, series 400, type 409B; Yellow Springs Instrument, 1725 Brannum Ln, Yellow Springs, OH, 45387.
b. DiGi-Sense thermistor thermometer; Eutech Instruments Europe BV, PO Box 254, 3860 AG Nijkerk, The Netherlands.
c. Laboratoires Clement-Thekan, Produits Burnet, 2 rue Chaintron, BP 850 92542, Montrouge, France.
d. Cryonic Medical SA, Le Martinet du Haut, 39110 Salins les Bains, France.
e. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.