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Field Torso-Warming Modalities;

a Comparative Study Using a Human Model

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Running Head: Field Torso Warming

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ABSTRACT

Objective: To compare four field-appropriate torso warming modalities, that do not require AC electrical power, using a human model of non-shivering hypothermia.

Methods: Five subjects, serving as their own controls, were cooled four times in 8ºC water, for 10-30 minutes. Shivering was inhibited by Buspirone (30 mg) taken orally prior to cooling and IV Meperidine (1.25 mg/kg) at the end of immersion. Subjects were hoisted out of the water, dried, insulated and then underwent 120 min of either: spontaneous warming only; a charcoal heater on the chest; two flexible hot water bags (total 4 liters of water at 55°C, replenished every 20 minutes) applied to the chest and upper back; or two chemical heat pads applied to the chest and upper back. Supplemental meperidine (maximum cumulative dose of 3.5 mg/kg) was administered as required to inhibit shivering.

Results: Post-cooling afterdrop was compared to spontaneous warming (2.2°C) less for chemical heat pads (1.5°C) and hot water bags (1.6°C, $p < 0.05$), and was 1.8°C with the charcoal heater. Subsequent core rewarming rates, the hot water bags (0.7°C/h) and the charcoal heater (0.6°C/h), tended to be higher than chemical heat pads (0.2°C/h, $p = 0.055$) and was significantly greater than spontaneous warming (0.1°C/h, $p < 0.05$).

Conclusion: In subjects with shivering suppressed, greater sources of external heat were effective in attenuating core temperature afterdrop whereas sustained sources of external heat effectively established core rewarming. Depending on scenario and available resources, we advice to use charcoal heaters, chemical heat pads or hot

water bags as effective means for treating cold patients in the field or during transport to definitive care.

Introduction

The main objective for pre-hospital care of patients exposed to a cold environment, either through cold air or cold water immersion, is to reduce cold stress and avoid further heat loss, thereby diminishing the risk of cold induced cardiac or respiratory failure. Initial measures should be taken to insulate the patient from the ground, remove wet clothing if possible and contain endogenous heat production within a vapor barrier and adequate wind- and waterproof insulation. Application of some form of exogenous heat should then be considered to reduce the depth and duration of the core temperature (T_{co}) afterdrop and establish a steady moderate (T_{co}) rewarming rate.<1-7>

For the mildly hypothermic victim (T_{co} = 35-32°C), who is physiologically stable spontaneous warming due to shivering heat production provides reduction of afterdrop and establishes a safe and efficient rewarming rate. <2, 3, 8-13> Several studies on mildly hypothermic shivering subjects have found that exogenous skin heating attenuates shivering heat production by an amount equivalent to the heat donated.<8-13> Accordingly, body-to-body warming,<9, 11> forced air warming, <10> application of electrical and hot water perfused heating pads<11, 12> or a charcoal heater<8, 13> have produced reduction of afterdrop and established rewarming rates similar to spontaneous shivering alone. Thus in a mildly hypothermic shivering victim, external warming generally does not decrease afterdrop or increase rewarming rate, however it might provide other advantages including increased comfort, decreased cardiac work and preserved substrate availability.

When shivering is diminished or absent in moderate (T_{co} = 32-28°C) to severe (T_{co} < 28°C) hypothermia or otherwise impaired due to the overall medical condition of the patient (i.e. old age, alcohol or drug ingestion, head or spinal injury, severe trauma or depleted metabolic energy substrates) some form of exogenous external or internal heat is required, otherwise afterdrop will continue and little or no rewarming will occur. This was demonstrated using a human model for non-shivering hypothermia, where meperidine was administered to inhibit shivering in mildly hypothermic subjects.<14, 15, 16> With metabolic and thermal responses similar to actual severe hypothermic conditions, subjects using spontaneous warming only experienced an increased afterdrop with rewarming either attenuated or eliminated compared to subjects recieving an exogenous heat supply.

In a summary of survey responses from 41 Mountain Rescue Association teams the most common protocols for treatment of hypothermia were chemical heat pads (46%), body-to-body warming (39%), and hot water bottles applied to the trunk (32%).<17> Although chemical heat pads and hot water bottles are commonly used and advised, scientific verification of their effectiveness is minimal or non-existent. In fact, these measures are recommended in some pre-hospital treatment guidelines <4, 6,> while discouraged in others.< 7, 18> Effective pre-hospital field warming is considered of utmost importance to improve the medical condition of severely hypothermic patients on admission to the emergency room.<1-7> It is therefore important to quantify the thermal effectiveness of those modalities which could be used in the field by laypersons, search and rescue (SAR) personnel or the emergency medical services (EMS) system.

We therefore decided to use the human model for non-shivering hypothermia<14, 15> to evaluate the thermal effectiveness of chemical heat pads and hot water bottles. To increase the surface area in contact with the skin, flexible nylon water bags were used instead of rigid bottles. For comparative reasons the previously evaluated charcoal heater and spontaneous warming were selected. The torso warming modalities are all suited for pre-hospital field care, being portable and requiring no external electrical power.

Methods

Design, setting and subjects

The study was approved by the Education/Nursing Research Ethics Board of the University of Manitoba. Five male subjects volunteered for participation (Table 1). They were without history of narcotic allergy or current use. Written informed consent were obtained from all patients. Studies were conducted in the Laboratory for Exercise and Environmental Medicine at the University of Manitoba during February and March 2006.

INSERT TABLE 1 HERE

Monitoring

Esophageal temperature (T_{es}),<22, 23> oxygen consumption (V_{O2}), respiratory exchange ratio (RER), electrocardiogram (ECG), heart rate (HR) and arterial oxygen saturation were continuously monitored and recorded during the trials as described previously.<14, 15> Endogenous heat production was calculated from V_{O2} and RER according to the following equation: M (W) = V_{O2} (l/min) x 69.7(4.686 + [(RER – 0.707) x 1.232]

Kommentar [OH1]: Referens?

Skin heat transfer (Q_{skin}; $W \cdot m^{-2}$) and skin temperature (°C) were measured from 12 sites using thermal flux transducers (Concept Engineering, Old Saybrook, Conn.).

Skin heat transfer for a specific body part ($Q_{body\ part}$; W) were then calculated using heat flux values for each transducer (W/ m^2) according to the following equation:

$Q_{body\ part}$ (W) = transducer flux (W/m^2) x BSA (m^2) x body part percentage, where

the body part percentage was estimated according to Layton et al. <24>

Intravenous (IV) access was obtained in the right forearm or hand for the purpose of drug and/or saline administration.

Protocol

Each subject served as their own control for comparative evaluation of each of the warming modalities, and was cooled at the same time of day on 4 separate occasions. The order of the trials followed a balanced design. Subjects dressed in a bathing suit and sat quietly at an ambient temperature of approximately 22°C for 10 minutes of baseline data collection after monitors were applied. To enhance the effect of meperidine, buspirone (30 mg orally) was taken during the instrumentation period. They were then immersed to the level of the sternal notch in a stirred water bath. The temperature of the water was lowered, by rapid inflow of 2°C water from a large reservoir, from 21°C to 8°C over a period of 5 minutes. Subjects were immersed for between 10 to 30 minutes depending on their body mass, immersion time being based on experience done during prior pilot studies. Immersion time was the same for all conditions for each subject and limited by the amount of body cooling that could occur for which shivering could be successfully inhibited by the prescribed maximal dose of meperidine.

During the last ten minutes of immersion, subjects were administered 1.25 mg/kg of IV meperidine (diluted in five 2-ml aliquots and injected over successive 2-minute intervals). Subjects were then hoisted out of the water, towel dried and placed in a sleeping bag, head covered, for 120 minutes of rewarming. Post-immersion supplemental injections of meperidine to a maximum cumulative dose of 3.5 mg/kg were administered based on V_{O2} and subjects sensation of shivering in order to maintain shivering suppression. Each trial was terminated after 120 minutes, a duration sufficient to establish a steady rate of core temperature change. Subjects were then immersed in 42°C water until their T_{es} rose to a normothermic level.

Warming modalities

No exogenous heat source was used in the spontaneous warming trials. The materials and protocols for the warming modalities are as follows.

Charcoal Heater. The heater consists of a combustion chamber, charcoal fuel and a branched reinforced, but flexible, heating duct (Normeca AS, Oslo, Norway). and produces 250 W of heat (1800 kJoules over 120 minutes). The combustion chamber is placed on the subject's chest and the heating ducts are applied dorsally over the shoulders, and then anterior under the axillae to cross over the lower chest (Figure 1, top). The total skin contact area of the chamber (23 x 12 x 6 cm, 1100g) and ducts is about 1,500 cm^2. The heater was ignited and set to the "high" setting 15-30 minutes before being applied to the subject. The heater can produce maximum heat for ~8 hours. Subjects lay their hands on the heater during warming.

INSERT FIGURE 1 HERE

Hot water bags. Two 6-liter flexible water bags (Mountain Safety Research, Seattle, USA) were each filled with 2 liters of 55 °C water. This volume of water were used because a total of 4 liters was considered a realistic volume that could be heated in the field, and filled with this volume of water the water bags lied flat allowing virtually all of one side of it to contact the skin. Each bag (45 x 25 cm, 120 g) has a skin contact surface area of about 1,100 cm^2. A towel was placed between each bag and the skin to prevent burn injury. Subjects lay with one of the bags placed under their upper back, while the other bag was placed on the upper chest (Figure 1, middle). Every 20 minutes, both bags were refilled with 55°C water. Subjects lay their hands on the top of the chest water bag as soon as it was comfortable.

Chemical heat pads. Two chemical heat pads (Dorcas AB, Skattkarr, Sweden) were activated 2 minutes prior to use. Each pad (42 x 25 x 2 cm, 1,400 g) has a skin contact surface area of about 1,100 cm^2. Subjects lay with one of the pads placed under their upper back, while the other pad was placed on the upper chest (Figure 1, bottom). Surface temperature on the skin side of the pads reached ~50°C within 2 minutes of activation and then gradually declined. Initially a towel was placed between each pad and the skin to prevent burn injury. It was removed after 30 minutes as pad surface temperature had decreased to a level where skin temperature could remain below the threshold (~43°C) for burn injury.<25> Subjects lay their hands on the chest pad during warming.

Data Analysis

Data was compared using a repeated measures ANOVA with post hoc analysis with Fisher's protected least significant difference (PLSD) test to identify significant differences. Results are reported as means ± standard deviation (SD), and $p < 0.05$ was the threshold defined for statistically significant differences.

Results

Endogenous heat production

Metabolic heat production increased from 116 ± 17 W during baseline to 195 ± 51 W during the last 10 minutes before meperidine injection. Meperidine suppressed shivering with heat production returning to 114 ± 21 W during the first 40 minutes post-cooling and then subsequently falling to 97 ± 17 W throughout the remaining 80 minutes of warming. There were no differences in heat production for the different conditions.

Heart rate, respiratory rate and skin temperature

Heart and respiratory rate increased during cooling from baseline values of 74 ± 13 beats/min and 19 ± 5 breaths/min to 87 ± 19 beats/min and 21 ± 7 breaths/min respectively just before meperidine administration. Post-immersion heart and respiratory rate declined to 66 ± 13 beats/min and 17 ± 6 breaths/min respectively. There were no significant differences between the different conditions.

Skin temperature on the chest and upper back reached maximum values of 41.6°C for the charcoal heater, 42.3°C for the hot water bags and 42.8°C for the chemical heat pads.

Body core temperature

There were no significant differences in initial cooling rate (-10 to 0 min) for the different conditions. (Table 2 and Fig. 2). The post-cooling afterdrop compared to spontaneous warming (2.2°C) was significantly less for the chemical heat pads (1.5°C) and the hot water bags (1.6°C, $p < 0.05$), but not for the charcoal heater (1.8°C). The time to T_{es} nadir was significantly less for all other modalities compared to spontaneous warming ($p < 0.05$). Subsequent core rewarming rates for the hot water bags (0.7°C/h) and the charcoal heater (0.6°C/h), tended to be higher than for the chemical heat pads (0.2°C/h, $p = 0.055$) and were significantly greater than spontaneous warming (0.1°C /h, $p < 0.05$).

INSERT TABLE 2 HERE

INSERT FIGURE 2 HERE

Exogenous heat delivery

The heat gain during active warming on the chest and upper back (each being 9% of body surface area) is shown in Figure 3. The charcoal heater provided a steady heat gain primarily to the chest. The water bottles donating heat to both the chest and upper back, heat transfer being slightly greater on the back than the chest, transiently increased each time water was replaced,. The chemical heat pads also donated heat to both the chest and upper back, the amount of heat transferred decreasing for the initial 30 minutes. Once the towels were removed heat transfer transiently increased and then again decreased to minimal levels over the next 90 minutes. During spontaneous warming there was a small continous steady heat loss from the upper torso. Total cumulative energy transfer to the chest and upper back during 120 minutes of warming was 536 ± 56 kJ for the hot water bags, 246 ± 71 for the chemical heat pads, 230 ± 50 for the charcoal heater and -50 ± 28 for spontaneous warming and this was significantly different for each of the warming modalities except chemical heat pads vs. charcoal heater ($p < 0.05$).

INSERT FIGURE 3 HERE

Discussion

This study was unique in that it used a human model for non-shivering hypothermia to evaluate relative efficacy of torso-warming procedures that could be used in the field and during transport to hospital. Hot water bags and chemical heat pads, which to our knowledge have not been quantified before, reduced both the amount and duration of the subsequent afterdrop following removal from cold stress. The charcoal heater had little effect on afterdrop amount compared to spontaneous warming, although it significantly shortened the duration of the afterdrop. Hot water bags and the charcoal heater then both provided efficient and steady rewarming rates whereas the rewarming rate was small with chemical heat pads and almost negligible with spontaneous warming.

Possible mechanisms for findings

When the amount of heat accessible is limited such as in a prehospital setting external heat should be applied to the torso and areas with high surface heat transfer (axillae, neck and groin).<4-7, 11, 12, 16> In a previous torso warming study, where different modalities of forced-air warming were compared to a charcoal heater and body-to-body rewarming, application of heat to the torso effectively decreased afterdrop and increased core rewarming.<16> This is likely due to the close proximity of the heat source(s) to the heart and lung circulation, and that skin blood flow on the torso is generally unaffected by temperature, unlike the distal arms and legs. In this present study all heat sources were therefore applied to the upper torso. Although the evaluated heat sources were similar in providing their heat content conductively to the skin and underlying tissues, there were some important differences, which affected warming effectiveness. Hot water bags and chemical heat pads, with their high initial heat delivery to a relatively large surface area, were both effective in attenuating afterdrop amount and duration. The charcoal heater with its similarly high heat production but smaller surface area had less effect on afterdrop amount compared to spontaneous rewarming, although it too significantly shortened the duration of the afterdrop. Heat delivery from the chemical heat pads then gradually declined and therefore the subsequent core rewarming rate was small. Hot water bags and the charcoal heater on the other hand provided high continuous heat delivery and rendered effective rewarming rates. Conclusively, high initial heat delivery to a large surface area effectively decreased the afterdrop whereas consistent high heat delivery was required for core rewarming.

Practical Implications

Several pre-hospital guidelines and review references recommend active pre-hospital warming of cold patients especially if the patient is severely hypothermic and endogenous shivering heat production is inhibited.<1-7> Previous studies have shown that non-shivering moderate-to-severely hypothermic patients have a distinct thermal disadvantage because their shivering heat production defense is abolished and their basal metabolic rate is lower than normal, thus the post-cooling afterdrop will be large and protracted.<14-16> In mildly hypothermic shivering patients, where exogenous skin heating attenuates shivering heat production by an amount equivalent to the heat donated, the application of external heat, although it might not decrease afterdrop or increase the core rewarming rate, <8-13> might provide other important advantages including increased comfort, decreased cardiac work and preserving substrate availability. Accordingly, the application of external heat might also be beneficial for initially normothermic victims exposed to a cold environment.

In non-shivering hypothermic subjects, this study demonstrated that chemical heat pads and hot water bags significantly decreased afterdrop at an amount of about 0.6 – 0.7°C and that the charcoal heater and hot water bags significantly increased the rewarming rate compared to spontaneous rewarming by 0.5 – 0.6°C/hr. All of the torso warming modalities also significantly decreased the time to Tes nadir and the reversing of core cooling from about 88 minutes with spontaneous rewarming to about 46 – 51 minutes with active warming.

Previous retrospective analysis of trauma registries <26, 27> as well as prospective clinical studies <28, 29, 30> have reported significant changes in physiologic variables, such as increased oxygen consumption, depletion of energy stores, disruption of blood clotting mechanisms, increased fluid resuscitation requirements, immune suppression and development of organ failure already at mild hypothermic states compared to normothermic trauma victims. Mild hypothermia is also demonstrated to increase the risk of death in trauma patients, independent of injury severity. <26, 27, 31> A significant correlation between decreased duration of hypothermia by active core rewarming and increased likelihood of successful resuscitation and survival after trauma has also been demonstrated. <28> Thus, diminishing or even reversing a fall in core temperature, in an efficient, yet safe manner is therefore desirable already in the field and during pre-hospital care and transportation in order to improve the patient's condition upon admission to the emergency department. Accordingly, although the clinical significance of the differences in core temperature afterdrop or subsequent rewarming rate measured in this study is not yet fully known, we believe the impact of these pre-hospital torso warming modalities might be of great benefit for an already compromised patient. To confirm the clinical significance of our findings we encourage further prospective interventional clinical trials.

All of the evaluated torso warming modalities are portable, require no external power supply and can easily be used by laypersons, SAR personnel or EMS crew without significant training. The charcoal heater has a durable design yet lightweight, is easy to handle even under harsh conditions and provides heat over 8-12 hours using only one charcoal fuel cell at high (250 W) settings. In protracted evacuation and rescue operations the charcoal heater therefore has the advantage of sustained heat production.

Water bags are often available during backcountry excursions or expeditions and do not take extra space or effort to transport. Although certainly possible and realistic for one person to reheat 4 litres of water every 20 minutes as in this study, an external heat source and significant effort are required for replenishing the water bags. They would therefore be more appropriate for scenarios where the patient will remain on the scene of the accident waiting for evacuation.

Chemical heat pads are somewhat heavier and takes up more space than the other modalities but can easily be brought in a vehicle such as in ground or air ambulance units. Being effective in reversing the initial fall in body core temperature, chemical heat pads might prove valuable for initial thermal stabilization of a cold victim. However, since the energy content is limited, for continuous heat delivery we would recommend that the chemical heat pads are replaced about every 30 minutes just as with the hot water bags.

Limitations

In order to limit the amount of meperidine necessary to inhibit shivering, we had to try to expose the subjects to the same relative cold stress depending on their physical constitution and therefore, based on experiences from prior pilot studies, immersion time differs between the subjects. However, since each subject served as its own control and immersion times were exactly the same for each subject for all the warming modalities this should not have any impact on our data.

Conclusion

In non-shivering hypotermic subjects , all warming modalities significantly reduced the time to reversing of core cooling and greater sources of external heat, such as chemical heat pads or hot water bags, were effective in attenuating the amount of core temperature afterdrop, whereas sustained sources of external heat, such as hot water bags or the charcoal heater, effectively established steady efficient core rewarming. Depending on scenario and available resources, these promising results support the advice to use charcoal heaters, hot water bags or chemical heat pads as effective means for treating cold patients in the field or during transport to definitive care.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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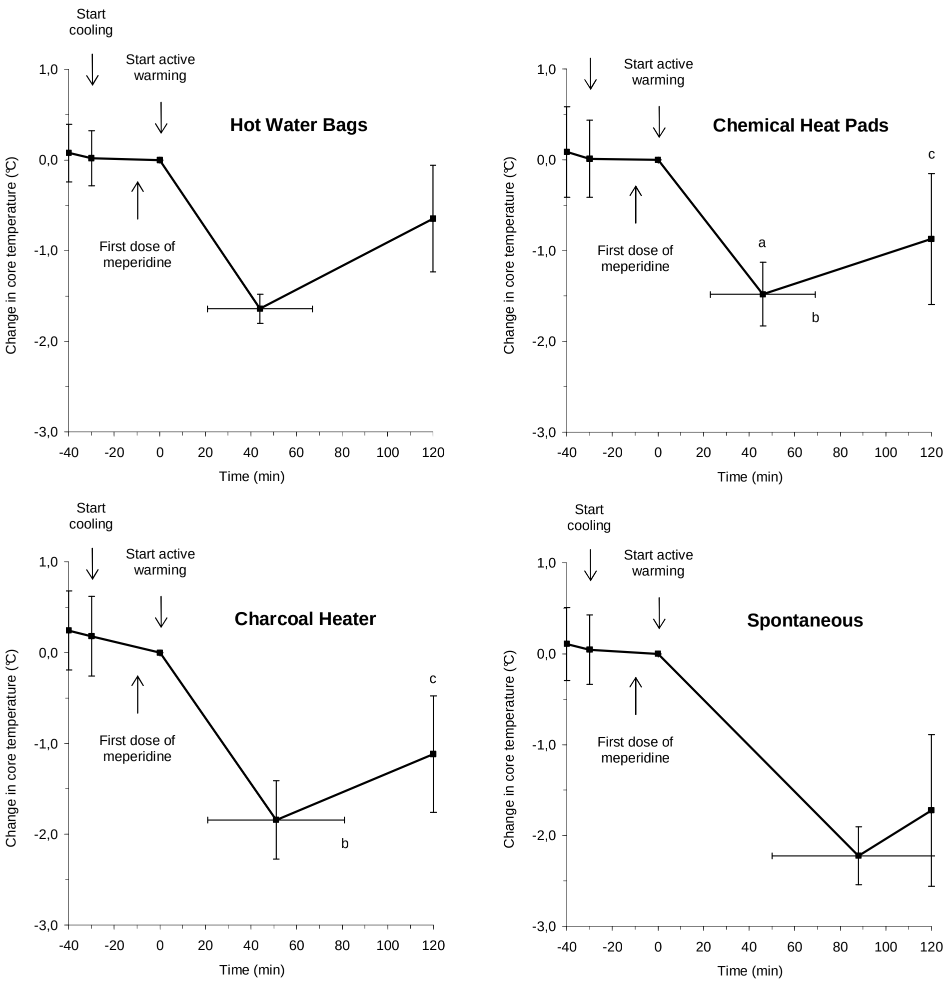
Figure Legends

Figure 1. Top; Charcoal heater in use. Middle: Hot water bags in use. Bottom: Chemical heat pads in use.

Figure 2. Change in esophageal temperature, T_{es}, during four warming protocols (mean, n=5). [a] Afterdrop amount and [b] time to T_{es} nadir less than Spontaneous; [c] final T_{es} significantly greater than Spontaneous; [d] final T_{es} significantly greater than Charcoal Heater ($p < 0.05$).

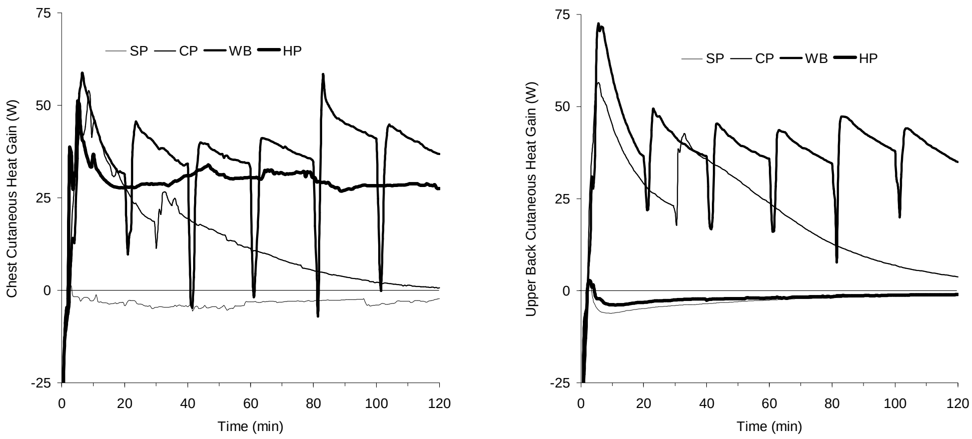
Figure 3. Cutaneous heat gain on the chest and upper back during four warming protocols (mean, n=5). WB = Hot water bags (note the saw tooth pattern due to replenishing the water); HP = Charcoal heater; CP = Chemical heat pads; SP = Spontaneous.

Figure 1.



Start cooling
Start active warming
Hot Water Bags
First dose of meperidine
Change in core temperature (℃)
Time (min)
Start active warming
Chemical Heat Pads
First dose of meperidine
a
b
c
Start cooling
Start active warming
Charcoal Heater
First dose of meperidine
b
c
Start cooling
Start active warming
Spontaneous
First dose of meperidine

Figure 2



75
50
25
0
-25
Chest Cutaneous Heat Gain (W)
SP
CP
WB
HP
0
20
40
60
80
100
120
Time (min)
75
50
25
0
-25
Upper Back Cutaneous Heat Gain (W)
SP
CP
WB
HP
0
20
40
60
80
100
120
Time (min)

Figure 3.

Table 1. Characteristics of subjects

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Subject	Sex	Age, yr	Height, cm	Weight, kg	Body fat,[a] %	BSA,[b] m^2	BMI,[c] kg/m^2
1	M	35	174	78	26	1.9	26
2	M	27	173	91	29	2.1	31
3	M	40	175	110	30	2.2	36
4	M	29	180	73	21	1.9	22
5	M	28	175	68	13	1.8	22
Mean		32	175	84	24	2.0	27
SD		6	3	17	7	0.2	6

BSA = Body Surface Area; BMI = Body Mass Index; SD = standard deviation.
[a] Calculated according to Durnin and Womersley.<19> [b] Calculated according to Dubois and Dubois.<20> [c] Calculated according to McArdle et al.<21>

Table 2. Core Temperature Responses

Table 2. Core temperature responses

Modality	Cooling rate (-10 to 0 min), °C/hr	Afterdrop amount, °C	Time to T_{es} nadir, min	Rewarming rate (60-120 min), °C/hr	Change in T_{es} (0-120 min), °C
Charcoal Heater	-0.8 (1.4)	-1.8 (0.4)	51 (30)[a]	0.6 (0.5)[a]	-1.1 (0.6)[a]
Hot Water Bags	-0.8 (1.3)	-1.6 (0.2)[a]	44 (23)[a]	0.7 (0.3)[a]	-0.6 (0.6)[a, b]
Chemical Heat Pads	-0.4 (1.6)	-1.5 (0.4)[a]	46 (23)[a]	0.2 (0.3)	-0.9 (0.7)[a]
Spontaneous	-0.9 (1.7)	-2.2 (0.3)	88 (38)	0.1 (0.8)	-1.7 (0.8)

Values are mean and standard deviation. T_{es} = esophageal temperature.
[a] Significantly different from Spontaneous ($p < 0.05$).
[b] Significantly different from Charcoal Heater ($p < 0.05$).