EFFICACY OF FORCED-AIR AND INHALATION REWARMING IN HUMANS DURING MILD (T_{CO}=33.9 "C) HYPOTHERMIA

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INTRODUCTION

In general, the study of field treatment for immersion hypothermia in human volunteers has been limited because ethical consideration usually limits the decrease of core temperature (T,) to 35 "C. Under these conditions of mild hypothermia, subjects shiver vigorously. Because exogenous external application of moderate sources of heat warms the skin and inhibits shivering heat production, these methods provide little advantage when vigorous shivering is present (1).

We previously used a human model for severe hypothermia in which mildly hypothermic subjects were given meperidine to abolish shivering (2). We compared the rewarming efficacy of a newly developed Forced-Air Warming System that provided a large amount of heat transfer (almost 300 W) (Forced-Air Warming), inhalation of heated **(43** "C) saturated air (Inhalation Rewarming), and spontaneous rewarming without shivering (Control) in cold (-20 "C) ambient conditions **(3).** Forced-Air Warming resulted in a decreased afterdrop and sixfold greater rewarming rate than Control or Inhalation Rewarming. Even though Inhalation Rewarming provided a warmer inspiratory temperature (T_{insp}) by > 60 "C, it did not provide any advantage over spontaneous warming over 150 min while the high heat donation of Forced-Air Warming rewarmed the subjects to normothermia within 50 min.

Because the Forced-Air Warming System was so effective in non-shivering subjects, we wished to see if the high amount of convective heat donation would be advantageous in vigorously shivering subjects who were cooled to lower T, than usually studied (i.e., < 35 "C). This provided an opportunity to restudy Inhalation Rewarming in shivering subjects at lower T, Morrison et al. **(4)** demonstrated that the rate of rewarming was inversely related to T_{co} at end of cooling. However, there were no controls in this study and it is not known if higher rewarming rates at lower T, demonstrate an advantage of Inhalation Rewarming or merely represent the higher shivering thermogenesis.

Therefore we evaluated T_{co} recovery in field-like conditions (T_a = -20°C) *(5)* while employing: 1) Endogenous Rewarming (no exogenous heat donation) (Control); 2) Inhalation Rewarming (Res-Q-Air', HT 1000 Inhalation Delivery System); and **3)** Forced-Air Warming with a newly developed system that provides a high amount of convective heat transfer (200-280 W).

METHODS

Four males and 1 female of average fitness participated in the study. *All* subjects underwent medical screening and gave written informed consent.

Core body temperature was monitored at the esophagus (T_{es}). Skin temperature and heat **flux** were monitored at 12 sites and the area-weighted means were calculated. Oxygen consumption ($\dot{V}O_2$), heart rate and blood pressure were monitored continuously.

The new Forced-Air Warming System consisted of a mobile insulated wooden **box** (1.6 m long **x** 0.725 m wide by **0.33** m high) with a nylon webbing stretcher (2.14 m long) supported on top. With the subject lying on the stretcher, a wire frame (curved side-to-side) was placed over the subject. The rostral portion of the **box** was hollow and contained two electric heaters and *6* circulating fans below the webbed stretcher. Two more heaters and 3 fans were contained in an enclosed section on top of the wire frame just above the subject's chest. **A** down sleeping bag was then placed over the wire frame. The head of the subject (which was exposed to ambient conditions) was covered with a down hood. The system configuration allowed exposure to air of all anterior skin surfaces, and posterior skin surfaces **from** mid thigh to the shoulders. When the heaters were used, the circulating fans were activated and the heaters were thermostatically controlled to maintain ambient temperature within the box at approximately 46-48 "C.

Each subject was cooled on three occasions separated by at least 3 days. Trials were conducted at the Same time of day. Baseline **data** were collected over 10 min at an ambient temperature (T_a) of 22 "C. Prior to immersion the subject was dressed with a thin plastic body suit. This suit ensured that the subject was *dry* following water immersion (which minimized evaporative heat loss during rewarming without the time consuming and mechanically stimulating process of towel ***drying).*** Using a mechanical hoist, the subject was transferred and immersed to the clavicles in 22 "C water. Water was then rapidly cooled to **3** °C within 15 min by the addition of ice. Average immersion time was 80 min. The subject was then hoisted out of the water, and the body suit was removed.

In order to control for external variables, each subject was placed in the rewarming **box** (and fitted with long thinsulate insulated **boots** up to the knee, **and** mitts up to the elbows) for each of the **3** treatment conditions. The box was then transferred to a temperature controlled chamber at T_a of -20 °C where either: 1) the subject breathed ambient air (-20 "C) with no exogenous heat donation (Control); 2) the subject breathed warm humidified air (43 "C) (Inhalation Rewarming); or 3) the subject breathed ambient air (-20 "C) with the Forced-Air Warming System activated (Forced-Air Warming). Rewarming duration was continued for a maximum of 150 rnin or until T_{es} reached 36.8°C.

RESULTS

Cooling phase

Baseline T, (–37.01 "C), T_{sk} (–30.73 "C), $\dot{V}O_2$ (–334 ml·min^{-1}) and ventilation (11.2 L·min^{-1}) were similar for each condition. T, at end-immersion (80 min) was 34.04 ± 0.64 (SD) °C, 34.07 ± 0.65 "C, 33.71 ± 0.39 "C in Control, Inhalation Rewarming and Forced-Air Warming conditions respectively while $\dot{V}O_2$ and ventilation increased to –1.3 L·min^{-1} and 31.0 L·min^{-1} respectively.

Table 1. Rewarming parameters for the three experimental conditions.

Condition	Afterdrop Amount ("C)	Afterdrop Length (rnin)	Rate of Rewarming (°C·hr^{-1})
Control	0.60 (0.2)	18.1 (4.7)	3.1 (1.0)
Inhalation Rewarming	0.48 (0.2)	14.1 (5.1)"	3.8 (1.0)
Forced-Air Warming	0.69 (0.4)	16.9 (6.0)	6.1 (0.4) t

(Mean ± SD, * < Control and Forced-Air Warming, † > Control and Inhalation Rewarming, $p<0.05$)

Rewarming phase

The afterdrop of T, for Control (0.60 ± 0.25 "C), Inhalation Rewarming (0.48 ± 0.19 "C) and Forced-Air Warming (0.69 ± 0.44 "C) conditions were not significantly different (Table 1). This corresponded to a similar time to reach the nadir in T, for Control (7.1 ± 2.2 rnin), Inhalation Warming (6.0 ± 1.4 min) and Forced-Air Warming (5.5 ± 3.6 min) respectively. However, the length of the afterdrop was significantly shorter for Inhalation Rewarming (14.1 ± 5.1 min) than Control (18.1 ± 4.7 min) and Forced-Air Warming (16.9 ± 6.0 rnin) ($p<0.05$). Rewarming rate was much greater ($p<0.05$) during Forced-Air Warming (6.1 ± 0.98 °C·hr^{-1}) than Control and Inhalation Rewarming (3.1 ± 0.96 and 3.8 ± 0.98 °C·hr^{-1} respectively).

Total heat loss throughout Control and Inhalation Rewarming was about 40 W. In comparison, Forced-Air Warming provided a total heat gain of between 160 and 280 W. After 30 rnin of rewarming, T_{sk} during Forced-Air Warming was –34.0 °C (3.3 "C above baseline) while T_{sk} for Control (–25.7

"C) and Inhalation Rewarming (–26.2 "C) were 5.0 "C and 4.5 °C below baseline respectively ($p<0.0001$). In all conditions $\dot{V}O_2$ was elevated during initial rewarming and then gradually decreased. The average $\dot{V}O_2$ during the total rewarming period was 4.0, 3.8, and 2.4 times baseline values for Control, Inhalation Rewarming and Forced-Air Warming, respectively ($p<0.05$). After 30 min of rewarming, $\dot{V}O_2$ had decreased to baseline values for Forced-Air Warming but remained elevated ($p<0.05$) above baseline for the other two treatments. Similarly, at the end of the rewarming period ventilation remained elevated for Control (25.4 $L \cdot min^{-1}$) and Inhalation Rewarming (24.1 $L \cdot min^{-1}$) while decreasing to baseline values for Forced-Air Warming (10.7 $L \cdot min^{-1}$).

CONCLUSION

Forced-Air Warming was able to rewarm subjects who were capable of vigorous shivering at twice the rate of shivering alone, indicating that the high heat transfer (160-280 W) was enough to more than make up for the inhibition of shivering heat production. We found that during Inhalation Rewarming the high ventilatory rates accompanying vigorous shivering, resulted in lower T_{insp} than the non-shivering conditions of our previous study (i.e., 37 *vs* 43 "C) (3). The small difference between T_{insp} and T_{co} may therefore help explain why Inhalation Rewarming did not provide any rewarming advantage over shivering alone.

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