A PORTABLE, RIGID FORCED-AIR WARMING COVER FOR PRE-HOSPITAL TRANSPORT OF COLD PATIENTS

G.G. Giesbrecht, **P.** Prithpal and X. Xu

Laboratory for Exercise and Environmental Medicine,
Health, Leisure and Human Performance Research Institute,
University of Manitoba, Winnipeg, Canada, R3T 2N2

INTRODUCTION

Field care of the cold patient can be divided into two phases: **(1)** rescue/non-vehicular transport and (2) vehicular transport. During the first phase, there are limited rewarming methods as exogenous heat *can* only be delivered by heat pacs, human bodies, warm water bottles or if available, inhalation of heated humidified air. The possible heat sources during vehicular transport, however, may be **more** numerous if the rescue/transport vehicles have sufficient power.

One warming therapy that has been recently developed in the last decade is forced-air warming. This method was used to warm vigorously shivering hypothermic subjects. Compared with shivering only, forced-air warming decreased the post-cooling afterdrop by 30% although the rewarming rate was unchanged **(3).** In a clinical study, however, forced-air warming has been shown to almost double the rewarming rate in emergency department care of moderately-to-severely hypothermic patients who were likely not shivering (4). We have since used a more powerful prototype of a forced-air warmer in shivering subjects and demonstrated no advantage, compared with shivering, for prevention of post-cooling afterdrop but a significant increase in rewarming rate from 3.4 to $5.8°C \cdot h^{-1}$ (5).

We have recently developed a human model for severe hypothermia where inhibiting shivering with meperidine (up to **2.5** $mg \cdot kg^{-1}$) considerably increases core temperature afterdrop, and the core does not rewarm spontaneously for up to **3.5** h **(6). Using this** model, we have shown that forced-air warming decreases the post-cooling afterdrop by almost 50% and produces a six-fold increase in the subsequent rewarming rate (7). Based on this data we have proposed the development of a forced-air warming system that could be used during emergency transport of cold subjects in the air (airplanes, helicopters), at sea (coast guard cutters, ships) or on land (ambulances, etc.).

We therefore felt that an appropriate system would include an existing commercial heating unit combined with a new forced-air cover that would include the following criteria: rigidity to prevent collapse; compactness for storage; ability to be rapidly assembled; of relative inexpense and the ability to accept a heating hose **from** existing heating units. The goal would be for the new cover to provide at least **as** much heat to the skin **as** the existing soft blanket covers.

Portable Rigid Forced-Air Cover (PORIFAC)

The prototype is made out of corrugated plastic (CORFLAST) and neoprene. The one-piece unit is constructed so that it can be collapsed by folding the side and end panels over each other. When folded, the unit is very flat for easy storage (3 cm X 103 cm x 40 cm). The unit unfolds to dimensions of 30 cm X 93 cm X 62 cm to fit over the patient's torso and upper legs. Neoprene collars at each end create a snug seal around the head and legs. Structural integrity of the unit is maintained by fastening the end and side panels together with Velcro™ strips. The rigid cover has holes (5.5 cm diameter) cut in the head end and above the abdomen to provide two options for attaching the hose from the heating unit; the hole not used for heat input is covered. One other similar-sized hole is placed in the head end to allow continuous airflow over the skin in order to maximize convective heat transfer. Two designs were tested; cross sectionally the comers were either square or tapered.

METHODS

On one occasion, 5 healthy normothermic subjects (4 males, 1 female), age 29.8 ± 7 years, weighing 78 ± 13 kg and 177 ± 8 cm tall were instrumented according to our standard practices (6) for continuous measurements of skin temperature and heat flux (loss) at 7 sites for calculation of average skin temperature ($\bar{T}_{sk}$) and total heat flux. Also, air temperature was measured at the input site and 1 cm above each skin site to calculate heat transfer coefficients (in $W \cdot m^{-2} \cdot {}^{\circ}C^{-1}$) for the total system ($HTC_{Total\ System}$) and at the skin level ($HTC_{At\ Skin}$), respectively.

The Bair Hugger 505 heating unit (Augustine Med Inc.) was used with both the PORIFAC and the regular commercial warming blanket (Model 300 Full Body Blanket; Augustine Med Inc.) to compare the heat transfer capability of these covers. In a single study, a balanced design was used to warm subjects during five 15-min periods of warming with the same heater/blower used with the following "coverheat input location" conditions: soft blanket/foot end, rigid tapered cover/abdomen, rigid tapered cover/head end, rigid square cover/abdomen and rigid square cover/head end. Between each heating period, electric fans were used to return skin temperature and total heat flux to baseline values (~15 min). Core temperature was not measured during these studies as subjects were normothermic, and the emphasis was on measurement of heat delivery by each system.

Repeated measures ANOVA was used to compare group values for each condition ($\alpha = 0.05$). The Fisher PLSD test was used for post-hoc analysis of significant differences.

RESULTS

The rigid cover, with heat input at the abdomen, provided similar heat delivery to the standard soft blanket, although the skin temperahue under the cover was significantly higher in this condition (Table 1). The heat transfer coefficient, measured at the skin level, was greater with the standard soft blanket than all

Table 1. Heat delivery parameters[1] for five "cover/heat input" configurations.

Cover/ Input Location	Heat Flux (W)	$\bar{T}_{sk}$ (°C)	$T_{AIR\ at\ skin}$ (°C)	$HTC_{Total\ System}$ ($W \cdot m^{-2} \cdot °C^{-1}$)	$HTC_{At\ Skin}$ ($W \cdot m^{-2} \cdot °C^{-1}$)
Blanket/ Foot	71* (11)	36.8 (0.4)	38.7 (0.6)	6.5 (1.1)	28*† (2.7)
Rigid Tapered/ Abdomen	67* (8)	37.5* (0.3)	40.2* (0.5)	8.8* (1.7)	23.4* (3.5)
Rigid Tapered/ Head	61 (7)	37.2 (0.4)	40.0* (0.4)	6.7 (0.9)	17.7 (1.9)
Rigid Square/ Abdomen	72* (8)	37.7* (0.3)	40.4* (0.5)	9.0* (0.9)	25.1* (4.9)
Rigid Square/ Head	60 (15)	37.1 (0.5)	39.7* (0.4)	6.6 (1.6)	18.1 (2.3)

[1] Values shown are means with SD below in parentheses, HTC, heat transfer coefficient.

* Significantly greater than unmarked column values ($p<0.05$).

† Significantly greater than all other conditions except tapered/abdomen ($P < 0.05$).

other configurations except the rigid square cover/abdomen configuration. This demonstrates the efficient, even distribution of air under the sof? blanket. However, when the HTC was calculated for each total system (i.e., using input temperature), the highest values were obtained with the rigid covers with heat input at the abdomen. This is consistent with a greater concentration of warm air to the upper body area in this condition and less heat loss through the top of the rigid cover than the soft standard blanket.

DISCUSSION

Clinical and experimental evidence indicates that warming cold patients during transport is likely beneficial, especially if severe hypothermia inhibits shivering. In this case, some type of heat may prevent a precipitous drop in core temperature. The fact that the rigid cover provides as much heat transfer as the standard blanket indicates that it would be useful to stabilize or increase core temperature during transport. The rigid cover is not sterile and would not be appropriate for perioperative use in the hospital, but it would be useful in emergency transport of cold patients. The tapered design is sturdier and is, therefore, recommended. Finally, heat transfer would be even more efficient when in practical use because a well-insulated rescue blanket could be used to encapsulate and better insulate the patient and rigid cover.

REFERENCES

1. Giesbrecht, G.G., Bristow, G.K., Uin, A., Ready, A.E. and Jones, R.A. 1987, Effectiveness of three field treatments for induced mild (33.0°C) hypothermia, *Journal of Applied Physiology*, 63, 2375-79.
2. Giesbrecht, G.G., Sessler, D.I., Mekjavic, I.B., Schroeder, M. and Bristow, G.K. 1994, Treatment of mild immersion hypothermia by direct body-to-body contact, *Journal of Applied Physiology*, 76, 2373-2379.
3. Giesbrecht, G.G., Schroeder, M. and Bristow, G.K. 1994, Treatment of mild immersion hypothermia by forced-air warming, *Aviation, Space and Environmental Medicine*, 65, 803-808.
4. Steele, M.T., Nelson, M.J., Sessler, D.I., Fraker, L., Bunney, B., Watson, W.A. and Robinson, W.A. 1996, Forced air speeds rewarming in accidental hypothermia, *Annuals of Emergency Medicine*, 27, 479-484.
5. Ducharme, M.B., Giesbrecht, G. G., Frim, J., Kenny G. P., Johnston, C. E., Goheen, M. S., Nicolaou, G, and Bristow, G. K., 1997, Forced-air rewarming in -20°C simulated field conditions, *Annuals of* the *New York Academy of Sciences*, 813, 676-681.
6. Giesbrecht, G.G., Goheen, M.S.L., Johnston, C.E., Kenny, G.P., Bristow, G.K. and Hayward, J.S. 1997, Inhibition of shivering increases core temperature afterdrop and attenuates rewarming in hypothermic humans, *Journal of Applied Physiologv*, 83, 1630-1634.
7. Goheen, M.S.L., Ducharme, M.B., Kenny, G.P., Johnston, C.E., Frim, J., Bristow, G.K. and Giesbrecht, G.G. 1997, Efficacy of forced-air and inhalation rewarming by using a human model for severe hypothermia, *Journal of Applied Physiology*, 83, 1635-1640.

ACKNOWLEDGMENTS.

Support NSERC Canada, and Augustine Medical Inc. Thanks to Ms. Gillian Weseen for assistance with data analysis. Portions of these data were presented in a paper at the NATO RTO Human Factors & Medicine Panel Symposium on Current Aeromedical Issues in Rotary Wing Operations, San Diego, CA, October 1998.