COMPARISON OF TWO REWARMING TECHNIQUES WITH A THERMAL WATER MANIKIN

M.B. Ducharme, G. Edwards and J. Frim

Defence and Civil Institute of Environmental Medicine
Toronto, Ontario, Canada, M3M 3B9

❦

INTRODUCTION

Traditionally, the efficiency of active surface warming techniques to rewarm hypothermic victims is evaluated on mildly hypothermic subjects by comparing the rate of increase in core temperature. The rewarming rates obtained with this approach, however, are contaminated by the endogenous heat production of the subjects, which makes the interpretation of the data difficult. An alternative method of evaluating active surface warming systems is with a thermal manikin. Very few studies, however, have used a manikin to quantify heat gain from a surface warming therapy despite the advantages it presents over human testing. Recently, Lackas et al. (1) compared several forced-air warming therapies by using a heat flux manikin (2) and concluded that his findings were supported by a similar study performed on humans (3).

The objective of the present study was to use a newly developed water-filled thermal manikin to compare the efficiency of two different surface warming approaches: a conductive heat transfer therapy (Heated Water Blanket; HWB) and a convective heat transfer therapy (Forced-Air Warming; FAW).

MATERIALS AND METHODS

The thermal manikin. Developed at the Defence and Civil Institute of Environmental Medicine (DCIEM), the water-filled thermal manikin consists of a full-scale, human-shaped manikin (head and arms excluded; weight of 67 kg; surface area of 1.5 m2) with a hard shell made of polypropylene having a thermal conductivity similar to that of the human vasoconstricted skin. The heat gain by the manikin is measured from the temperature increase of its components as sensed by 18 internal and 14 external temperature sensors and calculated by the following equation: $Q_{in} - Q_{out} = Q_{water} + Q_{components} - Q_{pump}$, where all Q's are rates of heat flow (W); Q_{in} and Q_{out} are rates of heat absorbed and lost by the manikin, respectively; Q_{water}, $Q_{components}$ are rates of heat gained by the water and the internal components of the manikin during the tests, respectively; and Q_{pump} is the rate of heat generation by the internal pump while in operation (61.4 W). The rates were calculated from the temperature changes, weight and specific heat of the different components of the manikin over time. Calibration of the manikin with the DCIEM Water Calorimeter showed that the measured heat gain by the manikin was on average within 3% of the calorimeter value for a variety of environmental conditions.

Surface warming therapies. The HWB therapy uses a conductive heat transfer approach. During this therapy, a cotton blanket (2.1 m long; 1.65 m wide) with a series of tygon tubing channels (5 mm outside diameter) sewn on its inner surface (about 110 channels@m-1) was used (Delta Temax; Pembroke, Ont, Canada). During the test, water controlled at 44°C was continuously circulated inside the channels of the blanket with a pump at a rate of 1.5 $L \cdot min^{-1}$. The water temperature was chosen to optimize the performance of the therapy while minimizing the risk of skin burn for a victim. During the test, the manikin was totally enveloped with the blanket and a down sleeping bag (13 clo insulation) and laid on a low density foam pad to optimize the contact between the blanket and the manikin's posterior surface.

The FAW therapy uses a convective heat transfer approach. During this therapy, a previously described FAW system was used (4,5). Briefly, it consists of a mobile insulated box with a nylon-webbing stretcher supported on top where the manikin laid. A series of heaters and fans located over and under the torso area of the manikin maintained the turbulent microenvironment of the system at about 46°C. The anterior torso area of the system was covered with a down sleeping bag (13 clo insulation).

Procedures. The tests consisted of measuring the heat gained and the time required to increase the mean temperature of the manikin from 25 to 37°C by using the two surface warming therapies. The tests were performed in a climatic chamber at three ambient temperatures of 20, 0 and -20°C. Before the test, the thermal status of the manikin was adjusted to 23°C by filling the manikin with 61 L of water at about 23°C and exposing the manikin to room temperature around 23 ± 1°C. The internal pump was then turned on and the temperature of the 32 sites were continuously recorded. The manikin was considered ready for the test when the average manikin temperature, calculated every minute, reached a value of 22.9 ± 0.3°C. The manikin was then transferred to the climatic chamber and rapidly positioned into a surface warming therapy within a 2-min period. This procedure did not significantly affect the mean temperature of the manikin. The warming therapy was then turned on and left operative until the average manikin temperature reached 37°C or a 3-h rewarming period had elapsed, at which point the test was terminated.

RESULTS

Table 1 shows the rate of rewarming and the rate of heat gain by the manikin during the two rewarming therapies at three ambient conditions. On average for the three ambient conditions, the FAW therapy had a rewarming efficiency 2 times larger (rate of rewarming: (mean ± SD) 6.2 ± 0.2 $°C \cdot h^{-1}$; rate of heat gain: 375.8 ± 17.8 W) than the HWB therapy (rate of rewarming: 3.1 ± 0.1 $°C \cdot h^{-1}$; rate of heat gain: 156.1 ± 10.8 W). The efficiency of the FAW therapy was about 7% lower at -20°C ambient condition as compared with the other two conditions. The efficiency of the HWB therapy was more affected by the ambient conditions, being decreased by 7 and 18% at 0 and -20°C, respectively, as compared with the 20°C condition.

Table 1. Rate of mean temperature increase* and average rate of heat gain of the manikin during two surface warming therapies at three ambient temperatures.

Ambient Temperature	FAW Therapy		HWB Therapy	
	Rate of Rewarming ($^\circ C \cdot h^{-1}$)	*Rate of Heat Gain (W)*	*Rate of Rewarming ($^\circ C \cdot h^{-1}$)*	*Rate of Heat Gain (W)*
20 °C	6.3	385.9	3.4	181.3
0 °C	6.3	386.3	3.2	168.5
-20 °C	5.9	355.2	3.0	149.1

*Rate of temperature increase measured from 25 to 37 °C

DISCUSSION

Two different surface warming approaches were compared in the present study: a conductive heat transfer therapy using a water circulating blanket (HWB) and a convective heat transfer therapy using FAW system. The two different therapies were set to generate similar microenvironment temperatures (44°C for HWB and 46°C for FAW) but were applied to different surface areas of the body. The HWB therapy covered the torso and legs while the FAW therapy was limited to the torso. Despite the advantage for surface coverage, the HWB therapy had a rewarming rate less than half of the FAW therapy, as measured by the water-filled manikin. The low performance of the HWB therapy is probably attributed to the limited, closed contact between the skin of the manikin and the heated blanket, despite the care taken to optimize the contact. On the other hand, the FAW therapy provided a good convection of warm air all around the torso for an optimal performance.

Despite the proper calibration of the water-filled manikin against the DCIEM Water Calorimeter, one may question the similarity in heat gain between human and manikin testing for the same rewarming therapy. From the testing results of the FAW system with human subjects (4), it was calculated that the heat gained by the subjects from the FAW system (heat from FAW = total heat from tissue temperature increase [heat from metabolism--heat loss]) increased the body tissue temperature by an average rate of $4.8^\circ C \cdot h^{-1}$. From the manikin testing, it was measured that the FAW therapy, when used under similar testing conditions, increased the average manikin temperature by $4.5^\circ C \cdot h^{-1}$, only a 6% deviation from the human results.

CONCLUSION

The results suggest that a thermal water manikin could be a valid tool to evaluate the efficiency of surface warming therapies for victims of hypothermia.

REFERENCES

1. Lackas, D.N., George Oakes, S., Gao, Y. and Sparrow, E.M. 1994, The use of a mannequin to assess forced-air warming systems by temperature measurement, in J. Frim, M.B. Ducharme and P. Tikuisis (Eds.), *The Sixth International Conference on Environmental Ergonomics, Proceedings*, (Toronto, Ontario:DCIEM), 198-199.
2. Shireman, B., Oakes, S.G., Iaizzo, P. and Sparrow, E. 1994, A heat flux manniquin instrumented with 28 thermal guarded calorimeters, in J. Frim, M.B. Ducharme and P. Tikuisis (Eds.), *The Sixth International Conference on Environmental Ergonomics, Proceedings*, (Toronto, Ontario:DCIEM), 180-181.
3. Giesbrecht, G.G., Ducharme, M.B. and McGuire, J. P. 1994, Comparison of forced-air patient warming systems for perioperative use, *Anesthesiology*, **80(3)**, 671-679.
4. Ducharme, M.B., Giesbrecht, G.G., Frim, J., Kenny, G.P., Johnston, C.E., Goheen, M.L.S., Nicolaou, G. and Bristow, G.K. 1997, Evaluation of infrared tympanic thermometers during normothermia and hypothermia in humans, in Clark M. Blatteis (Ed.), Thermoregulation, Tenth International Symposium on the Pharmacology of Thermoregulation, *Annals of the New York Academy of Sciences*, **813**, 225-229.
5. 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(5)**, 1635-1640.