

# A CALORIMETRIC VALIDATION OF EVAPORATIVE AND DRY HEAT LOSSES MEASURED WITH HEAT FLOW TRANSDUCERS

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**Introduction.** Heat flow transducers (HFTs) are small sensors typically used on humans to measure dry heat loss from the skin or from clothing. The validity of this instrument to estimate dry heat loss has been demonstrated (1, 2). However, the sensitivity of the instrument to measure evaporative heat loss during cold wet exposures has not been investigated. To which extend the instrument can estimate accurately the total skin heat loss (from dry and wet origin) during cold wet exposures is not known. The objective of the present study was to validate the use of HFTs for the estimation of the total skin heat loss from clothed subjects exposed to cold wet conditions with the direct calorimetric method. It was hypothesised that the evaporative component of the total skin heat loss will be underestimated when compared to the total skin heat loss as measured from the direct calorimetric technique.

**Methods.** Ten subjects (5 males, 5 females; age:  $27 \pm 6$  years; height:  $171.9 \pm 6.2$  cm; weight:  $74.2 \pm 9.8$  kg; surface area:  $1.87 \pm 0.14$  m<sup>2</sup>; body fat:  $25 \pm 9\%$ ) participated in the study. All subjects were informed of the details of the protocol, signed a volunteer consent form and participated in a familiarization session before their participation. The experimental protocol was approved by the Human Research Ethic Committee at the University of Ottawa.

The Snellen air calorimeter (direct calorimetry; 3), currently housed at the University of Ottawa, was used to estimate the total heat loss from subjects exposed to cold wet environments and was compared to the HFT method. During the trial, each subject was exposed to an ambient temperature of 7°C with 83% rh for a period of 120 min. During the first 30 min of exposure, the subjects were rested on a chair in the climatic chamber outside the Snellen air calorimeter in order to remove the heat stored in the shell of the body and thus decreasing the skin temperature. During the remaining 90 min, the subjects were sitting on a chair inside the Snellen air calorimeter maintained at the same ambient conditions. After 30 min in the calorimeter, when steady-state in the calorimeter was obtained (called the DRY period), the subjects were sprayed with 1 l of water to their clothing and were resting for another 60 min (called the WET period). The temperature of the sprayed water was the same as the air temperature of the calorimeter. At the end of the spraying, the clothing was saturated with water without dripping.

The subjects were dressed with the following clothing: cotton shorts, cotton t-shirt, one-piece cotton coverall, and cotton socks, in addition to neoprene gloves and boots and an

inflated lifevest (the lifevest was required to duplicate the conditions used in another study). The following parameters were measured continuously during the trials: rectal temperature with a rectal thermistor inserted 15 cm into the rectum (Mon-a-therm General Purpose Temperature Probe, Mallinckrodt Medical, St-Louis, MO, USA); heat loss from the skin and skin temperatures with 13 HFTs incorporating thermistors (model FR025-TH44033-F35, Concept Engineering, Old Saybrook, CT, USA) and positioned on the skin according to the modified Hardy & DuBois locations (4); dry and wet skin heat losses by direct calorimetry using the Snellen air calorimeter; and metabolic rate. Respiratory heat loss was estimated using a model using the ventilation rate, air temperature and rh data recorded during the trial (5).

The metabolic rate was measured with the open circuit technique using expired gas samples drawn from a 6 l fluted mixing box yielding an accuracy of  $\pm 0.25\%$  for rate of metabolic heat production. Expired gas was analyzed using electrochemical gas analyzers (AMETEK model S-3A/1 and CD 3A, Applied Electrochemistry, Pittsburgh, PA, USA) calibrated before each trial using gas mixtures of 4% CO<sub>2</sub>, 17% O<sub>2</sub>, balance N<sub>2</sub>. The turbine ventilometer was calibrated using a 3 l syringe. The Snellen whole-body air calorimeter was employed for the purpose of measuring whole-body changes in evaporative and dry heat loss, yielding an accuracy of  $\pm 2.3$  W for the measurement of rate of total heat loss (3).

The calorimeter was previously calibrated for rate of dry heat loss using a humanoid manikin heat source made of constant power zone heater cable ( $5.905 \text{ k}\Omega \cdot \text{m}^{-1}$ , Easy Heat ZH8-1CBR, New Castle, IN, USA); and for rate of evaporative heat loss using a precision tubing pump (Cole-Palmer, Masterflex 7550-30; Pump head 77200-50) delivering  $5 \text{ ml} \cdot \text{min}^{-1}$  ( $\pm 0.01 \text{ ml} \cdot \text{min}^{-1}$ ) of water to a heated 1200 W hotplate.

Paired t-tests were performed to test the differences between the heat losses during the DRY and WET periods inside the calorimeter. Significance was assumed for  $p < 0.05$ . The results are expressed as mean  $\pm$  SD.

**Results.** The mean skin and rectal temperatures of the subjects at the start of the exposure (T<sub>sk</sub>:  $30.1 \pm 1.4^\circ\text{C}$ ; T<sub>re</sub>:  $37.7 \pm 0.5^\circ\text{C}$ ) were significantly decreased at the end of the DRY (T<sub>sk</sub>:  $29.5 \pm 1.4^\circ\text{C}$ ; T<sub>re</sub>:  $37.1 \pm 0.5^\circ\text{C}$ ) and WET periods (T<sub>sk</sub>:  $26.2 \pm 1.2^\circ\text{C}$ ; T<sub>re</sub>:  $36.7 \pm 0.6^\circ\text{C}$ ) inside the calorimeter. At the end of the DRY period, the body heat storage decreased by an average of  $233 \pm 83$  kJ, and by an additional  $194 \pm 139$  kJ by the end of the WET period, as measured by direct calorimetry. The metabolic rate of the subjects averaged  $124 \pm 39$  W during the DRY period, and  $143 \pm 49$  W during the WET period.

Table 1 shows that at the end of the DRY period inside the calorimeter when 88% of the total body heat loss was dry, there was no significant difference ( $p \leq 0.05$ ) between the total skin heat loss (excluding the respiratory heat loss) as measured by direct calorimetry ( $170 \pm 23$  W) as compared to the total skin heat loss as measured by HFTs ( $165 \pm 25$  W). At the end of the WET period inside the calorimeter when only 59% of the total body heat loss was dry, there was no significant difference ( $p \leq 0.05$ ) between the total skin

heat loss (excluding the respiratory heat loss) as measured by direct calorimetry ( $175 \pm 30$  W) as compared to the total skin heat loss as measured by HFTs ( $196 \pm 32$  W).

*Table 1. Avenues of body heat losses as estimated by the direct calorimetric method using the Snellen Air Calorimeter and by heat flow transducers during exposure to a cold environment.*

	<i>Direct Calorimetry</i>	<i>Heat Flow Transducers</i>
<b>End of DRY period</b>		
Respiratory heat loss (W)*	$20 \pm 5$	-
Dry heat loss (W)	$166 \pm 24$	-
Wet heat loss (W)**	$23 \pm 4$	-
Total body heat loss (W)	$189 \pm 26$	-
Skin heat loss (W)***	$170 \pm 23$	$165 \pm 25$
<b>End of WET period</b>		
Respiratory heat loss (W)*	$21 \pm 6$	-
Dry heat loss (W)	$115 \pm 21$	-
Wet heat loss (W)**	$82 \pm 14$	-
Total body heat loss (W)	$196 \pm 32$	-
<b>Skin heat loss (W)***</b>	$175 \pm 30$	$196 \pm 32$

\* Respiratory heat loss was estimated by the model of Cain et al., 1990; \*\* Wet heat loss = Evaporative heat losses from the skin and the respiratory track; \*\*\* Skin heat loss = Total body heat loss – Respiratory heat loss.

**Conclusions.** We show that the use of HFTs for the measurement of the total skin heat loss from dressed human subjects exposed to a cold wet environment is a valid method. HFTs could measure the dry and wet heat lost components of the total skin heat loss with an accuracy comparable to the direct calorimetric method. Our hypothesis was rejected.

**Acknowledgements.** The authors would like to acknowledge the financial support from the National Search and Rescue Secretariat SAR New Initiative Fund under the project ‘Thermal Protection in Liferrafts: Assessment of Occupant Heat Balance and Development of Performance Criteria’ and Lawrence Mak from the National Research Council Institute for Ocean Technology in St-John’s, NF for his assistance in this project.

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