

ORIGINAL ARTICLE

Rewarming of healthy volunteers after induced mild hypothermia: a healthy volunteer study

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Objectives: The study compares the efficacy of two active and one passive warming interventions in healthy volunteers with induced mild hypothermia.

Methods: Eight volunteers were studied in a random order crossover design. Each volunteer was studied during re-warming from a core temperature of 35°C with each of: a radiant warmer (Fisher & Paykel); a forced air warmer (Augustine Medical), and a polyester filled blanket, to re-warm.

Results: No significant differences in re-warming rates were observed between the three warming devices. It was found that the subject's endogenous heat production was the major contributor to the re-warming of these volunteers. Metabolic rates of over 350 W were seen during the study.

Conclusions: For patients with mild hypothermia and in whom shivering is not contraindicated our data would indicate that the rate of re-warming would be little different whether a blanket or one of the two active devices were used. In the field, this may provide the caregiver a useful choice.

Patients presenting to emergency departments may be suffering from mild hypothermia.¹ In the emergency department there is often a conflict between the need to maintain core temperature and the need to expose the patient for full examination, which may also lead to hypothermia.² In some clinical situations, hypothermia has been shown to complicate treatment and recovery by increasing oxygen demand due to shivering,³ increasing the risk of wound infections,⁴ and affecting coagulation.⁵

To achieve and maintain normothermia, active warming methods are often used.⁶ Presently, the most common mode of active warming is by forced air devices. The efficacy of these devices in a range of settings has been widely reported.⁷⁻¹¹ A number of other warming techniques including heated blankets,¹² heated humidification,¹³ radiant lamps,¹¹ and electric blankets^{9, 14} have been used to re-warm patients. However, in some instances these devices have been shown to be less effective than forced air systems.^{9, 10}

This study compared the efficacy of the three warming interventions when used to re-warm healthy volunteers with induced mild hypothermia.

METHODS

After obtaining ethics committee approval and a signed, informed consent, 12 healthy volunteers were recruited. The study was conducted in a climate controlled room in the Middlemore Hospital intensive care unit. Temperature and relative humidity were maintained at 20°C and 50% respectively.

The studied interventions were the BairHugger forced air warmer (Augustine Medical Inc., USA), the PW810 radiant warmer (Fisher & Paykel Healthcare, Auckland, New Zealand), and a polyester blanket (748 g/m²). All volunteers were asked to participate on three occasions using each warming device in random order. Each of the study days were exactly 1 week apart to avoid any physiological adaptation to frequent cooling,¹⁵ and each patient was studied at the same time of day for each of his/her study days. The volunteers were clothed in light underwear only throughout the studies. Median age was 30 years, and median body mass index (BMI) was 22 kg/m².

Each volunteer had their core body temperature monitored continuously using both oesophageal and rectal temperature probes (Mon-a-therm 12Fr; Mallinckrodt, USA). The oesophageal probe was inserted nasally by an investigator after topical local anaesthesia. The probe was inserted a distance estimated to position the thermistor in the middle third of the oesophagus. The rectal probe was placed by the volunteer to a distance of 75 mm.

An indirect calorimeter (Deltatrack II; Datex, Finland) was used to monitor the volunteer's metabolic rate expired gas was collected by a fitted facemask. All measurements were recorded at 1 minute intervals using a National Instruments data acquisition card and a computer using LabView software.

Following the placement of the temperature probes, baseline recordings were made for a period of 20 minutes. During this time, the volunteer was covered with a hospital blanket.

Hypothermia was induced by immersing the volunteers up to their necks in a bath filled with water cooled to and maintained at 10°C. The bath was agitated regularly to minimise boundary layer effects. The volunteers were immersed until their oesophageal temperature decreased to 35°C. If this temperature fall had not been achieved after immersion for 60 minutes or if the subject was not able to tolerate the immersion, the experiment was abandoned.

Before re-warming, all visible water was removed from the subject's skin by gentle patting with a towel. The subject was then positioned supine on a standard hospital bed. The re-warming device was immediately applied, and re-warming continued until the volunteer's oesophageal temperature approximated the baseline, at which point the study was stopped.

The two active devices were applied in accordance with the manufacturer's user instructions. The radiant warmer was positioned 70 cm above the subject, and no attempt was made to prevent heat loss from exposed parts of the patient not beneath the warmer. The temperature of the skin under the radiant heater was controlled at 39.5°C using a servo

Abbreviation: BMI, body mass index

Table 1 Magnitude and duration of drop in oesophageal temperature after cooling finished

	Mean (SD) drop (°C)	Median time to minimum temperature drop (min)
Bair Hugger	0.59 (0.30)	6.5
F&P810	0.53 (0.19)	6.5
Blanket	0.54 (0.31)	7

feedback skin temperature sensor positioned on the sternum. Both devices were run for 10 minutes prior to re-warming.

The forced air warming device was used with a full body blanket (model 300), with the device was set to its high setting of 43°C. A cotton sheet was placed on top of the blanket.

The third warming device was a commonly available polyester filled blanket, 748 g/m². The patient was completely covered, except for the head.

Data analysis

For the purposes of analysis, the data for each of the re-warming episodes was smoothed using a five term moving average to lessen the potential for artefacts affecting the calculation of the rate of temperature increase. A multivariate analysis of variance was used to compare the rates of re-warming and the differences in metabolic rate.

RESULTS

Twelve volunteers were initially recruited for the study; four were subsequently excluded, as their core body temperature could not be cooled sufficiently by the described method. The eight remaining volunteers, (two women, six men) had a median age of 30 years (range 25–43) and a BMI of 22 (range 20–25).

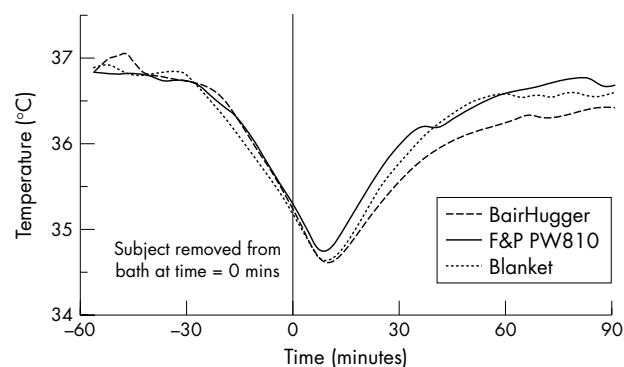


Figure 1 Mean oesophageal temperature for all subjects averaged after synchronisation at time cooling finished.

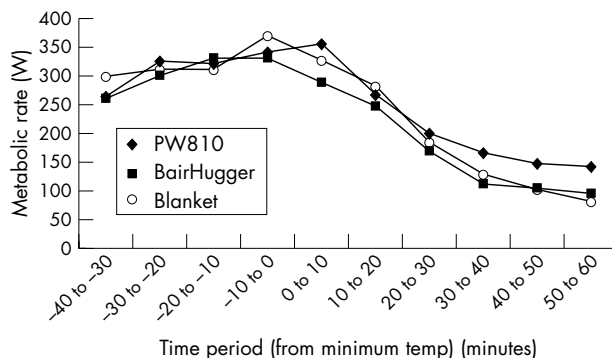


Figure 2 Metabolic energy production, average of all subjects.

At the start of re-warming, the core temperature continued to drop for a short time despite having commenced re-warming (table 1), the magnitude and duration of the drop was similar with all re-warming methods.¹⁶

As has been demonstrated in previous studies¹⁴ the rectal temperature lagged behind the oesophageal temperature, while showing a similar gradient.

The mean time to complete core re-warming (oesophageal temperature $\geq 36.5^{\circ}\text{C}$) was 50 minutes for the PW810, 105 minutes for the BairHugger, and 90 minutes for the polyester blanket (fig 1).

Comparison of re-warming rates

Analysis showed differences between patients ($p = 0.001$) and warmers ($p = 0.003$) using Wilk’s test. The difference in re-warming rates between the three warming methods reached statistical significance at the 20–30 minute time interval only, and only between the blanket and the BairHugger. Overall, there was no clear pattern indicating a difference between devices (table 2).

Comparison of metabolic rates

This graph suggests that patients warmed with the BairHugger tend to shiver less than do patients warmed with the blanket or PW810 (fig 2). The hypothesis of no difference in metabolic rate was tested using multivariate analysis of variance. The difference in average metabolic rates between patients was significant ($p = 0.001$) but the difference between warmers was not.

DISCUSSION

The re-warming rates that occurred with both active warming devices (the BairHugger and the PW810) were not significantly better than those achieved with the passive polyester blanket. There was a trend towards more rapid core re-warming with the PW810. There was a similar trend towards less metabolic energy production when re-warming with the Bair Hugger; we interpret this as a trend towards less shivering with this method. This emphasises the large contribution to re-warming made by the subjects’ metabolic heat production during the study. Indeed, the average

Table 2 Rates of re-warming for the four 10 minute periods after removal from the bath

Method	Mean (SD) rewarming rate in °C/min			
	0–10 min	10–20 min	20–30 min	30–40 min
BairHugger	0.021 (0.03)	0.057 (0.022)	0.037 (0.016)	0.027 (0.013)
F&P PW810	0.005 (0.038)	0.063 (0.018)	0.052 (0.012)	0.034 (0.009)
Blanket	0.016 (0.033)	0.061 (0.019)	0.045 (0.011)	0.038 (0.014)

metabolic energy produced, 300 W, was comparable to the total power output of the two active devices.

Differences in these re-warming methods not seen in our study may be revealed in a non-shivering model of re-warming.¹⁵ It is also possible that combined use of radiant heating without exposure of the non-irradiated skin would alter the interaction between heat transfer and shivering.

All three methods of re-warming (forced air, radiant warmer and polyester blanket) were well tolerated. No complications of re-warming were noted. Only small differences in re-warming rates could be found and these could be attributed to differences in metabolic rate. For patients with mild hypothermia, in whom shivering is not contraindicated, our data would indicate that the rate of core re-warming would be little different whether a passive insulator or one of the active devices tested was used. This may be applicable in the field where active devices are not always practical or available. If the therapeutic aim is to decrease shivering, it is possible that forced air re-warming will help achieve this, although in our study the trend was not significant.

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Competing interests: three of the authors work for Fisher & Paykel Healthcare Corporation, manufacturer of one of the devices tested

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