Bath rewarming from immersion hypothermia

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HOSKIN, R. W., M. J. MELINYSYN, T. T. ROMET, AND R. C. GOODE. Bath rewarming from immersion hypothermia. J. Appl. Physiol. 61(4): 1518-1522, 1986.—Trunk-only bath rewarming has often been recommended over whole-body bath rewarming as a method for the treatment of immersion hypothermia. At present, no report of a direct comparison of the relative merits of these techniques has been made. Authorities in favor of trunk-only bath rewarming base their proposal on the assumption that core temperature afterdrop would be minimized by preventing peripheral vasodilation when the subject's limbs are not immersed in the rewarming bath. In the present study, trunk-only and whole-body bath rewarming are compared by rewarming eight mildly hypothermic male subjects twice, once via each technique. It was concluded that trunk-only rewarming is not superior to whole-body bath rewarming as a therapy for mild-immersion hypothermia, based on the findings that no significant differences existed between the two techniques, either in size or duration of core temperature afterdrop, or in rate of rewarming.

cold water immersion; vasodilation

IMMERSION HYPOTHERMIA is a continuing problem in North America; recreational and commercial activities place ever-increasing numbers of people in situations where accidental cold water immersion is a risk. Drowning is classified as one of the three leading causes of accidental death; immersion hypothermia is known to facilitate the drowning process (15). The best method for the rewarming of victims of immersion hypothermia is still a subject of much controversy, and mortality of these victims remains high.

Bath rewarming has long been a popular method for rewarming from immersion hypothermia. However, it has been suggested that this technique may increase the core temperature afterdrop which occurs after removal of a hypothermic victim from cold water (7, 10, 14), possibly by causing a large, sudden vasodilation of peripheral blood vessels. It has been suggested that, if bath rewarming is to be used, the limbs be left out of the bath to minimize peripheral vasodilation. However, no direct test of this hypothesis has been reported in the literature. The purpose of this study is, therefore, to compare the thermal effects of whole-body and trunk-only bath rewarming in mildly hypothermic subjects.

METHODS

Eight male students gave their informed consent to participate as subjects in this study. Each subject was immersed on two occasions spaced at least 1 wk apart (to prevent acclimatization), but performed at the same time of day (to eliminate any possible circadian effects). An experiment consisted of immersion in a cold bath followed by either trunk-only or whole-body bath rewarming; the order of the experiments was randomized so that four subjects underwent trunk-only rewarming first, and four underwent whole-body rewarming first.

As no one core temperature measurement adequately represents the temperature of the entire body core (3, 18), three indexes of core temperature were measured. Esophageal temperature was measured by passing a thermistor (YSI 44004, Yellow Springs), sealed in the tip of a 1.5-mm-diam flexible polyethylene catheter, into the esophagus via the nose until the tip of the thermistor was 43 cm from the nostril (thermistor approximately at the level of the heart) (3, 12, 22, 29). Deep auditory canal temperature (Tdc) was measured with a YSI 4404 thermistor sealed in the tip of a 1.5 mm diam flexible polyethylene catheter. This was attached to the tip of a cotton swab (Q-tip, Chesebrough-Pond's), using a thin strip of masking tape, so that the tip of the catheter and the tip of the swab were even. Care was taken not to cover with tape the section of the catheter containing the thermistor bead. The probe assembly was slowly inserted into the subject's auditory canal until the subject experienced discomfort; the probe was then withdrawn 1-2 mm and fixed to the pinna of the ear with surgical tape. Cotton wool was carefully packed into and over the opening of the auditory canal; this was then covered with a wide piece of surgical tape. The probe was always inserted so that the thermistor bead was in contact with the anterior wall of the auditory canal. Rectal temperature (Tr) was recorded with a thermistor (YSI 401) inserted 15 cm past the anus.

Temperatures were displayed on a hand-held digital unit (Doric) that displayed temperatures to a resolution of 0.1°C. Core temperatures were recorded at 1 min intervals. Before the start of the experiment, the subject, clad in a bathing suit and covered with a blanket, sat quietly for 10 min while temperatures were observed to ensure that the thermistors were positioned securely and operating properly.

Following the equilibration period, the subject entered the cold bath. The water in the cold tank (dimensions 123 x 60 x 75 cm) was maintained at 15.0 ± 0.3°C (mean ± SD) and was well stirred to prevent thermal stratification. The subject sat in a harness that supported the limbs as well as the trunk, allowing the posture of the subjects to be standardized while permitting free circu-
loration of water around the subject. The water level in the
tank was maintained so that the subject’s shoulders were
just immersed.

For the first experiment on each subject, the cold
immersion was terminated after 1 h of cold immersion
had elapsed or after \( T_r \) fell to 35.5\(^\circ\)C or esophageal
temperature \( (T_e) \) fell to 35\(^\circ\)C, whichever came first. The
subject had the option of terminating the experiment at
any time if he so desired. For the second experiment, the
subject was cooled until the same drop occurred in \( T_r \) or
\( T_e \) as in the first cold immersion.

Following cooling, the subject climbed out of the cold
water bath and immediately entered the adjacent re-
warming bath (dimensions identical to those of the cool-
ing bath). The transfer was made with as little effort as
possible by the subject to avoid provoking any premature
vascular dilatation. The subject was suspended by a
harness in the warm bath such that his posture was
approximately the same in either rewarming protocol as
in the cooling bath. For whole-body rewarming, the subject
was immersed up to the neck; for trunk only rewarm-
ing, the legs and arms were elevated slightly and the
water level adjusted such that the trunk was immersed
to the armpits but \( T_r \) and \( T_e \) were out of the water. For all experiments,
the water was well stirred and was maintained at 40 ±
0.5\(^\circ\)C.

Webb (30) has pointed out that no core temperature
gives a reliable indication of the point in the rewarming
process when all of the heat lost by a hypothermic subject
has been restored. For this reason, the decision to dis-
tinue rewarming in the present experiment was based
mainly on the appearance of sweat on the forehead of the
subject (4, 20). At this point, \( T_r \) was typically 0.1
0.3\(^\circ\)C higher than its precooling value; \( T_e \) was invariably
below 38.5\(^\circ\)C when rewarming was halted.

Skinfold thicknesses were measured at three sites on
each subject (subscapular, triceps, and submammary) using
Harpenden skinfold calipers (John Bull, England). These
measurements were used to calculate an estimated value
for the percentage of the body weight of each subject
made up by fat using the method of Durnin and Wom-
ersley (5). These values, together with other pertinent
anthropometric data, are presented in Table 1.

RESULTS

All eight subjects tolerated the experiments reasonably
well. None of the subjects elected to terminate the ex-
periment due to excessive discomfort during either the
cooling or the rewarming phase. Statistical analysis was
performed using Student’s \( t \) test for paired observations;
significance was taken to be at a confidence level of 95% (\( P < 0.05 \)) unless stated otherwise.

Cooling rates were calculated from the data by per-
forming a least-squares linear regression on the tempera-
ture data for the cooling period. As the data showed a
good deal of fluctuation during the first few minutes of
cold immersion, data for the first 5 min were not included
in the analysis. Comparison of cooling duration, cooling
rate or size of temperature drop at any core site between
trunk-only rewarming and whole-body rewarming exper-
imental trials revealed no significant differences, so for
purposes of discussion the cooling data for all experi-
ments were combined (\( n = 16 \)). The mean temperature
responses at each of the three core sites for all eight
subjects are shown in Fig. 1. As cold immersion was
terminated as soon as a particular subject had experi-
enced a maximum permissible drop in core temperature,
different subjects underwent immersions of different du-
rations. Therefore, the mean core temperature responses
are shown only over the period for which all subjects
underwent cold immersion, i.e., the duration of the short-
est immersion (27 min for subject 3). The mean duration
of cold immersion was 41 ± 12.5 min (mean ± SD). Mean
temperature drops and cooling rates for \( T_r \), \( T_e \), and \( T_a \)
are presented in Table 2.

The ability of the two bath rewarming techniques to
rewarm the subjects was analyzed in three ways: rewarm-
ing rate and size and duration of afterdrop for each core
temperature recorded. Rewarming rate was calculated
for each core site by the same process used in calculating
the cooling rates.

![Figure 1](http://jap.physiology.org/)
The size of the afterdrop was defined as the difference between the temperature of a core site at the start of rewarming and the minimum temperature reached at that site. The duration of the afterdrop was defined as the length of time from the start of the rewarming period until the temperature had dropped, passed through its minimum and recovered to the temperature exhibited by that core site at the beginning of rewarming. These definitions of size and duration of afterdrop agree with those commonly used by most investigators (2, 9, 17, 19). Figure 2 illustrates the breakdown of a typical temperature profile for analysis in terms of rewarming rate and size and duration of afterdrop. The results of this analysis are presented in Table 3.

The mean responses of each of $T_{re}$, $T_{ac}$, and $T_{es}$ for all eight subjects during the two types of rewarming are shown in Fig. 3.

The magnitude of afterdrop was tested in each case to ensure that it was significantly different from 0. This was true in all cases except for $T_{es}$ in trunk-only rewarming, where the size of afterdrop was significant only for $P < 0.09$.

Comparison of rewarming rate and size and duration of afterdrop at each core site between the two bath rewarming techniques revealed no significant differences whatsoever at the $P < 0.05$ level.

Although the decision to terminate rewarming was based on several criteria (recovery of core temperatures to acceptable levels and appearance of sweat on the forehead) and therefore somewhat variable from one experiment to the next, a comparison was made of the mean duration of rewarming between the two methods studied. The mean duration of whole-body rewarming (26.9 ± 2.7 min) was found to be significantly less than the mean duration of trunk-only rewarming (35.2 ± 4.8 min).

**DISCUSSION**

Due to obvious ethical constraints, the degree of hypothermia induced in human subjects in any experiment of this type must be relatively mild. Although there is no reason to believe that comparable results would not be obtained in cases of severe accidental hypothermia, it must be realized that the results of any study involving mildly hypothermic subjects should be interpreted cautiously with respect to the situation of severe hypothermia.

The goal of any rewarming technique has been summarized as “the restoration of all lost heat without precipitating additional fatal side effects” (10). The two main problems associated with rewarming have been the continued fall of core temperatures following removal of a hypothermic victim from cold water (afterdrop) and deterioration of cardiovascular status following rescue.

The latter problem is due to the decreased cardiac output of the cold heart (16, 21) as well as the decrease in circulating plasma volume, with resultant decrease in blood pressure and increase in blood viscosity (25). The decrease in plasma volume is apparently due to increased urine production caused by an increased central blood volume resulting from peripheral vasoconstriction and hydrostatic “squeeze” of venous capacitance vessels (14).
and due to impaired tubular reabsorption by the hypothermic kidney (24). The cold myocardium is unusually susceptible to ventricular fibrillation (28); it has commonly been assumed that the major cause of death in victims of hypothermia is ventricular fibrillation (14), although more recent research does not support this conclusion, suggesting instead that death usually follows simple cardiac arrest (asystole) (26).

Afterdrop is considered to be dangerous primarily because of the increased risk of cardiovascular collapse at lower core temperatures. Many authors cite cases of victims being pulled from cold water while conscious and in seemingly good health only to lose consciousness and die during rewarming or during transport to a treatment facility. This “postrescue collapse” has been attributed to a decrease in core temperature from a relatively safe region of mild hypothermia to a more severe condition where central nervous function is depressed and cardiovascular status is poor, as described above. For this reason, some authorities are of the opinion that minimization of afterdrop is the prime consideration of a rewarming technique (9).

Two different theories exist for the mechanism responsible for afterdrop. The first theory, suggested by Golden and Hervey (8), maintains that afterdrop is due to simple conductive removal of heat from the body core by the colder external body shell. This theory is based on experiments in pigs, which showed similar afterdrop of \( T_{cw} \) between live, anesthetized pigs and those in which the circulation was stopped before rewarming by inducing cardiac arrest. The second theory holds that afterdrop is due to peripheral vasodilation caused by the application of heat to the skin; blood that perfused the cold peripheral vascular bed would return to the core at a low temperature, causing central temperatures to drop (1, 2, 21).

These two theories imply two different philosophies of rewarming technique. The first theory (conductive mechanism of afterdrop) would suggest that rapid addition of heat to the body periphery would quickly reverse the core-to-periphery thermal gradient, changing the situation to one where the core temperature is being raised by conductive transfer of heat from the surface. The second theory (convective mechanism of afterdrop) has assumed that rapid heating of the skin would result in massive peripheral vasodilation (1, 12); hence, heat should be added directly to the body core (13, 23), or, if surface heating is used, that the trunk only should be heated, the limbs being left out so as to minimize the presumed vasodilation (2, 4, 6, 7).

Until recently, no experimental evidence existed to validate these claims. Savard et al. (27) showed that immersion of a hypothermic subject in water at 40°C does not, in fact, produce a large or sudden increase in blood flow to the limbs. This suggests that the convective mechanism of afterdrop is not the major cause of core temperature afterdrop, although it may certainly be a contributing factor.

The results of the present study agree with this theory. Large differences in size or duration of afterdrop between trunk-only and whole-body rewarming would likely be due to different degrees of convective heat exchange between body core and shell regions; no such trend was apparent in the experimental data. Our data suggest that afterdrop is probably best explained by simple conductive transfer of heat through body tissue due to the thermal gradient which exists between core and shell regions.

This suggests that the best way to attack the rewarming problem is, as stated by Harnett et al. (10), by “overwhelming the temperature gradients within the victim’s body by a massive infusion of heat.” Bath rewarming affords a high rate of heat transfer to the subject, and although the results of the present study do not show a significantly larger rate of rewarming with whole-body as compared with trunk-only bath rewarming, the former method is simpler to implement and may produce a hydrostatic squeeze which compresses venous capacitance vessels, improving venous return to the heart and thus assisting cardiac output.

The fact that a higher rate of rewarming for the three core temperatures measured did not result with whole-body bath rewarming than with trunk-only rewarming might be contrary to the expected result, as a larger heat-exchange surface is exposed to the warm water with the former technique. However, it has been demonstrated that the major areas of heat transfer in the nude human are the neck, groin and sides of the chest (11). As the groin and thorax were immersed in both types of rewarming (the neck was not immersed during trunk-only rewarming), the rate at which heat would be absorbed by a subject would be similar for the two methods.

It was observed that a drop of approximately 0.2°C occurred in the \( T_{cw} \) and \( T_{es} \) between the last record taken in the cold water bath and first record made in the rewarming bath, over a time span of 1–2 min. This was assumed to be due to an exercise-induced increase in muscle blood flow and hence in convective heat transfer from core to periphery (27). Thus, it could be argued that the renal physiological afterdrop was the difference between the last temperature recorded in the cold bath and the lowest value recorded in the warm bath. For the sake of interest, the results were reanalyzed for size and duration of afterdrop using this new definition of afterdrop. As with the original and more widely-accepted definition of afterdrop, no significant differences between the two rewarming methods were observed when the afterdrop was determined according to the second definition.

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REFERENCES

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