TREATMENT OF ACCIDENTAL HYPOTHERMIA
(An Experimental Study of Inhalation Rewarming)

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INTRODUCTION

Accidental hypothermia in man is a common, but serious problem in cold air and water environments. The rapid rate of cooling which occurs in cold water immersion[12] and in mountain accidents[10, 23] can readily progress to a medical emergency. Hence immediate recognition and therapy of this condition are necessary to overcome its high mortality[6, 22].

Many current articles[9, 10, 16], medical texts[2] and military survival publications[8, 32] recommend rapid peripheral rewarming as the treatment of first choice for hypothermia. Indeed, this has been shown to be effective even in the profoundly hypothermic victim[1]. Many modalities are used to accomplish this, including immersion in hot water baths, wrapping in electric blankets, application of heated objects to the skin surface[3], and recently, circulation of warm water through special garments fitted to the victim[33]. These methods are all effective in treatment of rapid-onset hypothermia, but certain physiological problems may arise with active, peripheral rewarming of the slow onset, unconscious, profoundly-hypothermic victim. The well-described “afterdrop” of the core body temperature following removal of the cold stress can be increased in magnitude by peripheral rewarming. This occurs through vasodilation in the cold periphery and subsequent return of cooled blood to the body core, further chilling the myocardium[33] and potentiating the possibility of ventricular fibrillation[1, 17,33]. Furthermore, in hypothermia of long duration, in which intravascular volume is decreased secondary to fluid shifts, rapid rewarming may precipitate hypovolemic shock as peripheral vasodilation further diminishes central blood volume[17, 33].

To obviate these problems, some authorities[17,31] recommend rapid rewarming for rapid-onset hypothermia, and slow rewarming for slow-onset hypothermia. The difficulty in many accident situations of ascertaining the degree of hypothermia and its duration, complicates the decision of which type of therapy to apply, at a time when delay decreases the chance of successful resuscitation.

Theoretically, core rewarming of the hypothermic victim avoids the physiological hazards mentioned above, through delivery of heat directly to the central circulation and tissues, leaving the limbs and peripheral tissues to warm air alone[28] and in combination with heated, intravenous fluids[27]. Although all of these techniques have proven successful in many instances, they are clearly limited to the hospital environment.

Recently, Lloyd[20] has described a means of core rewarming through the airway using warmed oxygen. He presents case histories showing its effectiveness in the hospital treatment of hypothermic patients, and in addition, describes a portable apparatus based on this principle[21]. Inhalation rewarming is also receiving the interest of

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mountain rescue organizations[26] and of physicians associated with mountaineering medicine[15, 29].

Therefore, inhalation of heated, water-saturated gas (such as oxygen) by the hypothermia victim may best combine the merits of core rewarming and first-aid applicability at the accident site.

The purpose of this experiment was to compare the effectiveness of inhalation rewarming (using heated, humidified oxygen) to peripheral rewarming in a hot whirlpool bath. In order that the results be most relevant in accidental situations, immersions were conducted in the sea using persons of average build, who wore standardized clothing and life-jackets. In addition, a rewarming apparatus was selected so as to be compatible with rescue aircraft and vessels, such as those of the US Coast Guard.

MATERIALS AND METHODS

Immersions were conducted in the sea near Victoria, British Columbia, from on board a research ship which provided laboratory space for recordings and rewarming procedures. Sea temperatures were between 7 and 8°C and a slight current and small waves prevailed for the 4 days of immersions.

Ten healthy, male subjects (all athletically active) volunteered for the study and satisfied rigid, medical selection criteria described elsewhere[12]. Their characteristics (means and ranges) were: age 29 (20-48); weight 83 kg (75-105); height 1.84m (177-191); and percent body fat 15.4 (9.3-25.7) based on standard measures of skinfold thickness.

Core temperature was measured as follows. A fine, padded thermocouple was placed gently against the tympanum, and the auditory meatus sealed with a was plug. Rectal temperature was monitored with a thermistor inserted 15cm beyond the anus. In one subject only, oesophageal temperature was obtained using a thermistor inserted nasally and positioned to lie at about the level of the cardiac atria.

Production of hypothermia. Each subject wore an outfit of typical seaman’s clothing and a personal floatation device. With tympanic and rectal temperature being continuously monitored, 10 minutes of pre-immersion values were recorded. The subject then entered the cold sea water and remained motionless beside the ship while clinging to a life-ring. Constant visual surveillance of the subject was maintained. The immersion was terminated when the core temperature declined to 35°C or when the subject became too uncomfortable to continue. The range of immersion times was 45 to 120 minutes. The subject then climbed out of the water up a 3 meter ladder to the deck, removed his wet garments with assistance, and walked 20 meters to the rewarming site in the laboratory of the ship. The time interval from leaving the water to initiation of rewarming was 3 - 4 minutes.

Rewarming procedures. Each subject was cooled twice (on separate days) and rewarmed once by each of the two procedures. The older of use of the two rewarning procedures was randomized for the different subjects.

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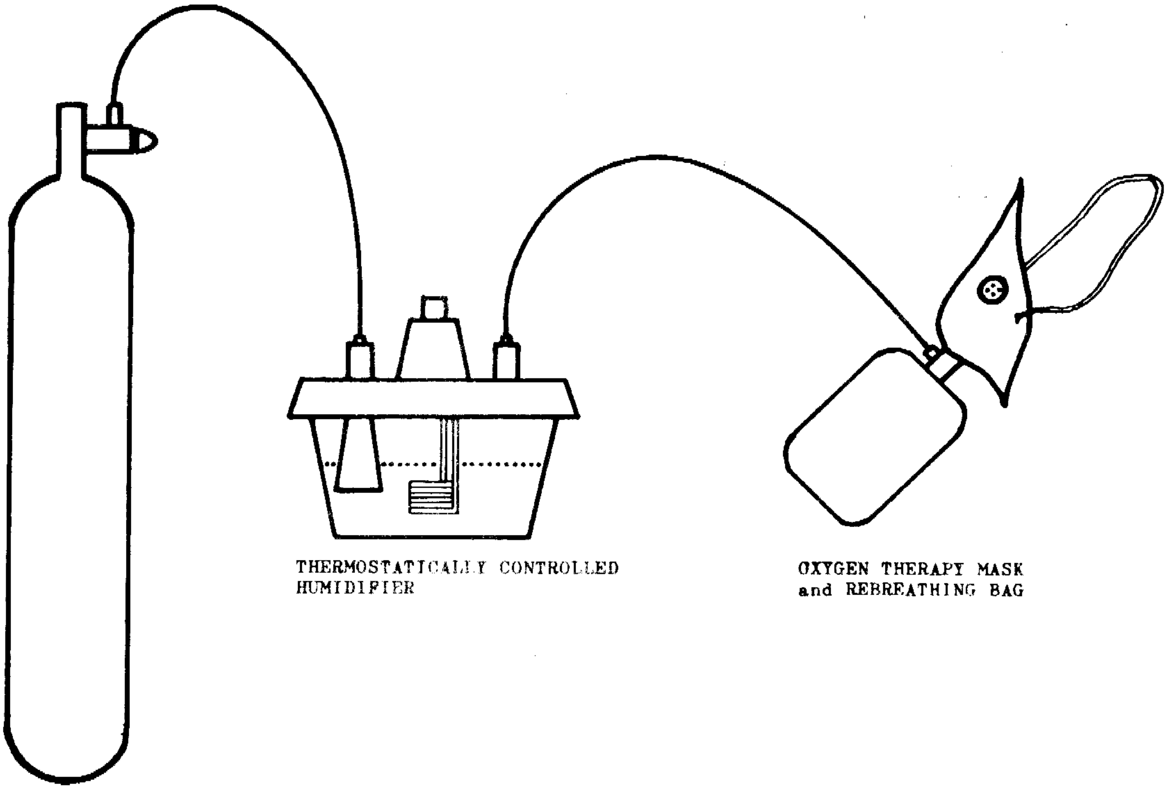


Figure 1 - Inhalation Rewarming Apparatus

Figure 1 shows the inhalation rewarming apparatus. Oxygen from the cylinder was passed at a variable rate through the heating and humidifying apparatus. It was a standard Bennett model heater and vaporizer commonly used on hospital respirators. It consisted of a 1-litre water bath with a thermostatically-controlled, electric, immersion-heater element. The oxygen was bubbled through the water and delivered to the subject via a loosely-fitted, ventilation mask. The mask was fitted with a rebreathing bag to act as a reservoir which helped conform the variable ventilation flow rate of the subject to the uniform flow of the oxygen. The water was heated to about 70°C such that the water-saturated oxygen flowed from the Bennett heater at about 55°C and arrived at the subject's mask at 40-45°C. This was the maximum temperature of inhaled oxygen that the subjects found to be comfortable. The flow rate of oxygen was regulated to maintain the 40-45°C temperature of the inhaled gas. This required high flow rates for the first 5-10 minutes, because the subjects had high ventilation rates associated with vigorous shivering thermogenesis. As shivering subsided, oxygen flow rates were reduced to 10-12 litres/min for the remainder of the rewarming. Inhalation rewarming was discontinued when the subjects had rewarmed about 1.5°C by tympanic recordings, involving a total period of about 45 minutes from initiation of the treatment. During the inhalation rewarming, the subjects lay prone on a foam mattress. Room temperature was 24-26°C. The subjects were exposed to the air until their skin temperatures in the trunk region reached air temperature, requiring 7-10 minutes. They were then covered with an unwarmed blanket for the remainder of the rewarming period.

Bath rewarming was accomplished using a 5 foot long, whirlpool bath. The subject reclined in the bath so that the water was at neck level. Initial water temperature was about 26°C and was then raised steadily to 42°C over the first 7-8 minutes. Vigorous stirring continued at this temperature for the remainder of the rewarming. The lower initial water temperature was required, due to the severe discomfort to conscious, hypothermic subjects if suddenly immersed at the higher temperature.

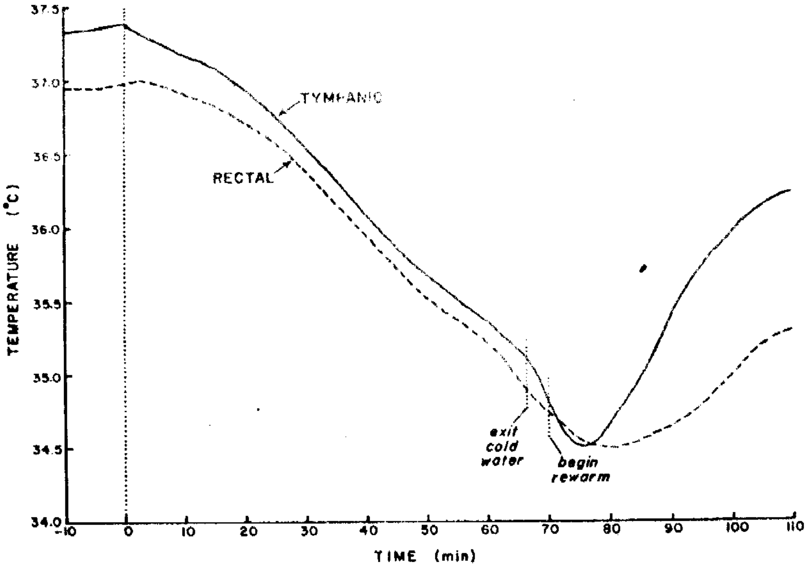


Figure 2 Typical recording of core body temperature during cooling in 7°C water and subsequent inhalation rewarming

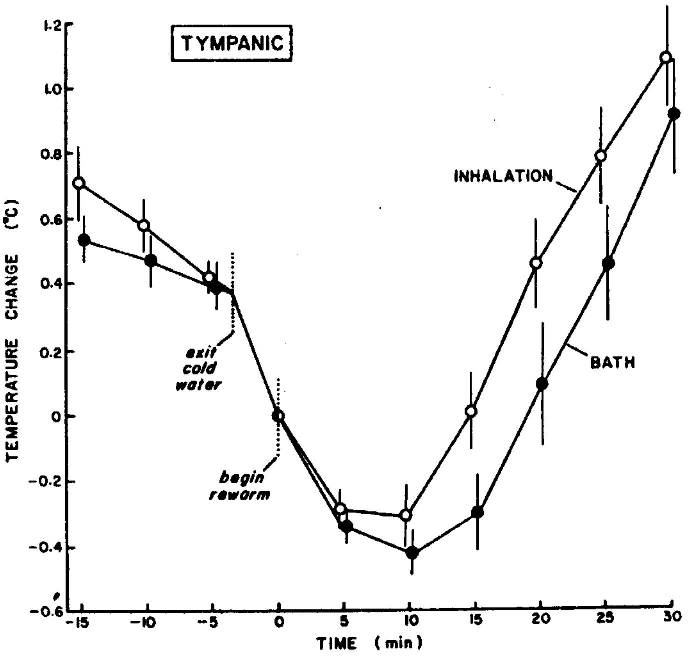
RESULTS

A typical recording of core temperature changes during cooling and inhalation rewarming of one individual is shown in figure 2. A fairly uniform cooling rate was established by approximately 20 minutes of immersion and the subject exited the cold water when the core temperatures were near 35°C. Temperatures continued to decline during the period before inhalation rewarming began, and this “afterdrop” continued for another 0.3°C ever the first 10 minutes of rewarming before being arrested. Temperature increase of the tympanic site proceeded at a faster rate than the rectal site.

For the ten subjects, comparison of the effectiveness of the inhalation and bath rewarming techniques is presented for the tympanic and rectal sites in Figures 3 and 4 respectively. Change in temperature before and after the onset of rewarming is shown. Tympanic temperature exhibited marked acceleration of cooling during the interval of physical activity that was associated with movement from the cold water to the rewarming laboratory. In this 3-4 minute period, tympanic temperature declined an average of 0.4°C. For the tympanic site, there was no significant difference in the amount of continued cooling with the two rewarming methods. Inhalation rewarming had a mean after-drop from commencement of rewarming of 0.38°C compared to 0.48°C for bath rewarming. The inhalation technique appeared to provide a slightly more rapid onset of increase in tympanic temperature. By 15 minutes of rewarming with each method, uniform rated of temperature increase were established, such that by 30 minutes of rewarming, a temperature rise of 1.3°C above the minimum was achieved.

Figure 3

Comparison of tympanic temperature changes occurring with inhalation and bath rewarming. Changes were calculated from the temperature at the beginning of rewarming (time 0). The mean tympanic temperature at time 0 was 34.5°C. The difference in cooling curves from 15 to 5 minutes before rewarming was due to clothing differences (being studied separately), and had no bearing on the afterdrop findings. Vertical lines denote standard errors of the means.



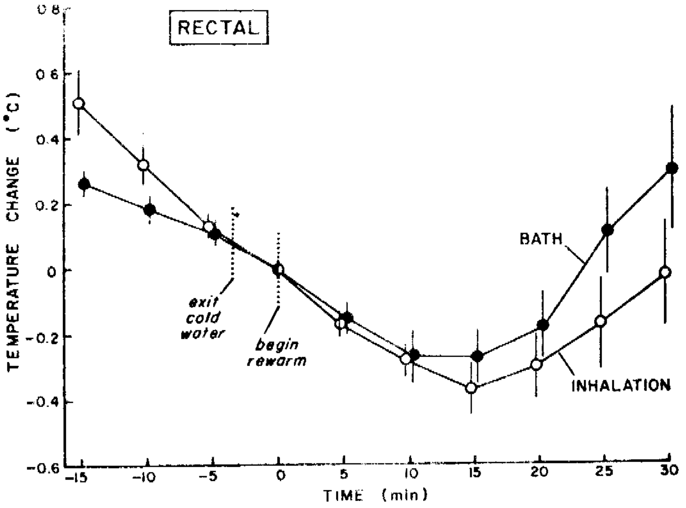


Figure 4

Comparison of rectal temperature changes occurring with inhalation and bath rewarming. The mean rectal temperature at time 0 was 35.3°C. Other conditions as in Figure 3.

Rectal temperature (Figure 4) showed less response to the physical activity during the transition from the cold water to the rewarming site (only a 0.1°C drop). Again, no significant difference occurred in the amount of after-drop between the two rewarming methods. With inhalation rewarming, there was a further mean after-drop of 0.40°C compared to 0.33°C with bath rewarming. At the rectal site, inhalation rewarming appeared to provide a slightly slower rate of temperature increase than bath rewarming. Approximately 20 minutes was required to establish a steady rate of temperature increase, such that at 30 minutes of rewarming, temperature rises above minimum of about 0.6°C and 0.4°C occurred for the bath and inhalation techniques respectively.

In comparing the rate of temperature increase of the tympanic and rectal sites during inhalation rewarming (Figures 3 and 4), rectal temperature increase was significantly lower than tympanic from 15 minutes of rewarming onwards.

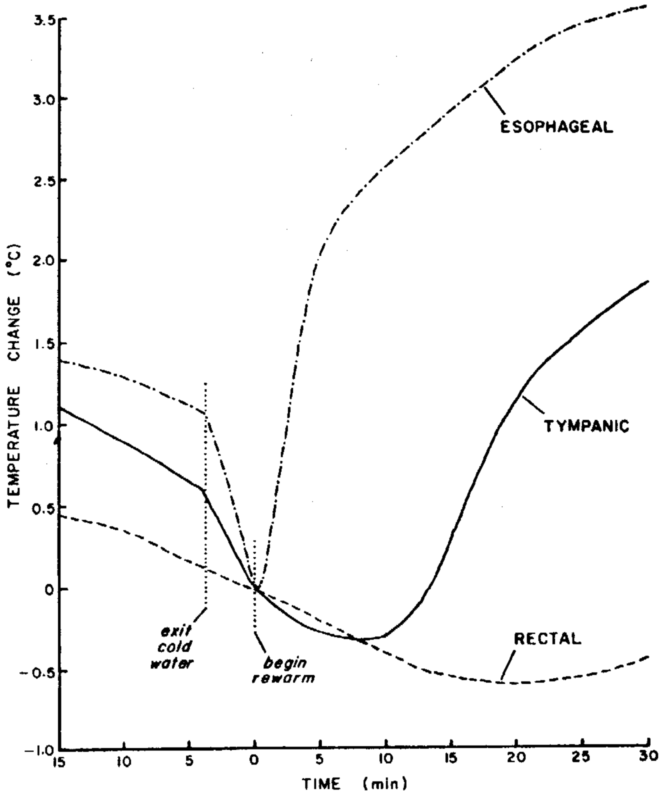


Figure 5

Changes in oesophageal temperature in comparison to tympanic and rectal temperatures in an individual being rewarmed by the inhalation method. The mean temperature of the three sites at time 0 was 34.1°C.

Figure 5 presents the temperature change curves for the one subject who has oesophageal temperature recording in addition to tympanic and rectal measurements. Oesophageal temperature showed essentially no after-drop once inhalation rewarming began. Furthermore, this site showed a rapid rate of increase in temperature, gaining 2.1°C in the first 5 min. Tympanic temperature showed a small after-drop of 0.3°C and onset of temperature increase in less than 10 minutes (similar to the pattern in Figure 3). Again, rectal temperature had a greater after-drop and slower onset of increase than tympanic when treated with the inhalation technique.

DISCUSSION

These experimental results confirm the theoretical expectation that inhalation rewarming can be an effective treatment for hypothermia in humans. The lack of difference in core temperature after-drop and rewarming rate between inhalation and bath rewarming allows the inhalation technique to be considered in "active" or "aggressive" therapy. Although cardiovascular variables were not measured, the lower rectal and skin temperatures, and the more persistent shivering with the inhalation method testify to less warming and consequently less vasodilation of the peripheral regions. Hence, the further advantage results that rewarming shock and induction of ventricular fibrillation by cold and aciduric venous return are minimized, despite rapid rewarming of the "critical core". With the inhalation method, direct warming of the brain would occur by conduction from the nasopharynx, and by circulation of warmed vertebral and carotid arterial blood. The more rapid rewarming of the brain would both reverse cold induced depression of the respiratory centres and more rapidly stimulate regaining of consciousness of the severely hypothermic victim.

With regard to the need to stop further cooling of the heart and begin its rewarming, the extremely rapid response of the oesophageal temperature to inhalation rewarming deserves emphasis. Previous studies have shown that a close parallel exists between oesophageal temperature and the temperature of the heart and great vessels[5]. The oesophageal recording would therefore indicate that inhalation rewarming facilitates rapid myocardial rewarming. Transfer of heat from warm, humidified gases to the airways is rapid[34]; and heat may then flow from the airways to other structures of the mediastinum. The heart would be warmed from the pericardium inward. Probably of greater significance, however, is the return to the heart of warmed blood from the lungs, leading to myocardial warming both. In cases of severe hypothermia, as you would not be moving the large pool of cold fluids in the peripheral regions, we assume that in a borderline survival case of hypothermia the inhalation rewarming would be superior to hot bath rewarming.

This was shown by CM Shanks and HM Marsh in their paper “Simple core rewarming in accidental hypothermia; a case treated with heat infusion, endotracheal intubation and humidification” (British Journal of Anaesthesiology: 45:1973:522-525). The subjects lay prone on a foam mattress, room temperature at 24-26°C, exposed to the air until their skin temperature in the trunk region reached air temperature, at which time they were covered by an unwarmed blanket.

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FISH BITES MAN

The fish were really biting when Chuck Gosgreve took his boat out off the Louisiana coast. A 33lb king mackerel bit his arm and he needed nine stitches. But the fish landed in the boat for the day’s biggest catch.

(Sunday Telegraph, 11 April 1971)