IMMERSION OF FOREARMS AND LOWER LEGS IN 45°C WATER EFFECTIVELY REWARMS MODERATELY HYPOTHERMIC SUBJECTS

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INTRODUCTION

In mild-to-moderate hypothermia, a condition in which victims shiver vigorously, the noninvasive application of exogenous heat inhibits this endogenous heat production, usually providing no advantage for minimizing afterdrop of core temperature (T_{co}) or augmenting subsequent rewarming rate. Vanggaard and Gjerlof (1) have proposed a simple rewarming technique that supplies exogenous heat by immersing hands, forearms, feet and lower legs in 44 to 45°C water.

Two previous studies have concluded that this method is ineffective (2,3). However, these results are likely due to discrepancies between the originally proposed procedure and the actual study protocols used. In both studies, water temperature was only 42°C, and the beat exchange area was confined to either the hands and forearms only (3) or hands and feet only (2). It is also noteworthy that subjects were only cooled to rectal temperatures of about 36.3°C.

The aim of the present work is to evaluate the efficiency of rewarming the blood returning centrally via the superficial veins of the hands, forearms, feet and calves following the procedure, as it was originally proposed by Vanggaard and Gjerloff (1). We hypothesized that compared to shivering-only conditions, extremity warming would effectively attenuate the post-cooling afterdrop and enhance subsequent core rewarming--the effect being proportional to the temperature difference between core temperature and of the rewarming water. We also expected extremity rewarming to inhibit shivering heat production with little or no adverse cardiovascular effects.

METHODS

Six subjects (1 female) (mean ± SD: age = 27 ± 8 yrs; height = 178 ± 11 cm; weight = 71 ± 12 kg) were studied after giving informed consent to an ethically approved protocol. Core temperature was monitored at the esophagus (T_{es}), aural canal (T_{ac}) and rectum (T_{re}). Electrocardiogram (ECG) and heart rate (HR) were monitored continuously and blood pressure was monitored at 5-min intervals with an automated blood pressure cuff. Metabolic and respiratory parameters were monitored at 30-s intervals. Cutaneous heat flux and temperature were measured from 4 sites on the distal limbs: hand, forearm, calf and foot.

Each subject was dressed in a bathing suit and cooled on 3 occasions, in 8°C water, to a T_{es} of 34.3 ± 1 (± SD)°C. Each subject was then rewarmed by 1 of 3 techniques following a balanced design: shivering only; immersion of **hands,** forearms, feet and lower legs in 42°C water; or immersion of hands, forearms, feet and lower legs in **45°C** water. During the shivering protocol, subjects were towel dried and placed in a vapor barrier bag within a sleeping bag. For the warm water immersion protocols, subjects were transferred, via the hoist, to a separate water tank and placed on a seat just above water level. They then leaned forward with their head resting on a support such that their legs and arms were immersed up to the knees and elbows. Treatment continued until either T_{es} increased to **37.0°C** or **90 min** had elapsed. T_{es} did not reach **37°C** within **90 min** in any of the shivering-only **trials.** During both **42** and **45°C** extremity rewarming protocols, subjects were removed fiom the warm water when T_{es} reached **37°C** and sat motionless covered by a cotton blanket for **30** more min.

Afterdrop (the difference between T_{es} on exit from cold water and its nadir), **length** of the afterdrop period and the **maximum** rate of rewarming were compared with repeated measures ANOVA. P **e 0.05** = significance.

RESULTS

Core temperature changes: The mean length of the immersion period was 61 **± 5 min,** and the T_{es} at the exit fiom cold water was **34.3 ± 0.8°C.** The afterdrop in T_{co} was decreased by both **42°C** and **45°C** water immersion **(0.4 ± 0.2°C)** compared to shivering **(0.6 ± 0.4°C).** The rate of rewarming was significantly greater with **45°C** water immersion **(9.9 ± 3°C·h⁻¹)** than both **42°C** water immersion **(6.1 ± 1°C·h⁻¹)** and shivering **(3.4 ± 2°C·h⁻¹).** Post-cooling, it took longer to initiate an increase in T_{co} with **42°C** water immersion **(17.9 ±** 6 **min)** compared to **45°C** water immersion (1**1.4± 2** min). It is likely that **42°C** water took longer to open the peripheral arteriovenous anastomoses. Thus, the length of the afterdrop period was shorter during the **45°C** water condition **(14.3** * **4** min) than during **42°C** water immersion **(21.2 ± 8** min).

In both extremity immersion protocols, T_{es} continuously rose at a constant rate until the extremities were removed from the warm water at a T_{es} of **37°C.** **This** took **–22** min in **45°C** extremity immersion and **–34** min in **42°C** extremity immersion. During the shivering-only protocol, the rate of rewarming gradually decreased as T_{es} rose and metabolic rate decreased. T_{es} did not reach **37°C** within **90 min** in any of the shivering-only trials.

After the warm water extremity immersion, the rapid increase in deep body temperature (T_{ac} and T_{es}) was followed by a drop **(~1°C)** in temperature, indicating an equilibration of temperatures withim the different body compartments mediated to the central circulating blood volume. This phenomenon was most pronounced in T_{es}, less in the T_{ac} and not in T_{re}.

Cardiovascular changes: No objective or subjective signs of circulatory failure were observed during extremity rewarming, neither when hoisting the body out of the cooling bath nor during the rewarming period. HR and blood pressure changes were within the normal range.

DISCUSSION

The proposed advantages of this method are twofold. First, warming of the distal extremities opens the arteriovenous anastomoses (AVAs) in the fingers and toes. Second, this greatly increases the venous return to the heart via superficial veins in the'forearms and lower legs. The AVAs are located almost exclusively in the distal parts of the extremities, most abundant in fmgers and toes (4). The AVA organ is placed in the skin at a depth of about 1 mm fiom the skm surface. The AVAs convey warm arterial blood to the superficial venous rete. This phenomenon creates a large heat exchange area, which can be used to deliver heat to the core when these areas are immersed in very warm water. In these experiments where subjects were cooled down to a deep body temperature of ~34°C, the opening of the peripheral circulation through the AVAs did not result in adverse circulatory responses.

One important consideration for this protocol is the possibility of bum injury to skin exposed to warm water. In the studies of Cahill et al. (3), exposure of the extremities to 45°C water was reported as extremely uncomfortable (too hot), thus necessitating the use of 42°C for rewarming. In the present study, subjects were allowed to immerse their extremities slowly with times ranging fiom 1 to 10 min. Any discomfort subsided after 10 to 15 min. In none of the subjects were there any sequelae to the exposure. The hyperemia of the exposed skin persisted for some hours, but there were no indications of any later untoward effects of the exposure. Therefore, in order to decrease initial discomfort and prevent burns, it may be advantageous to start with 42°C and gradually increase to a maximum of 44°C.

This method has been adopted by the Royal Danish Navy and included in the Danish Ship Captains Guide as a field method of rewarming in mild to moderate hypothermia. It is important to note that care must be taken not to bum the skin; therefore, for safety reasons, water should be no warmer than 44°C.

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