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BRIEF REPORT

Comparison of Distal Limb Warming With Fluidotherapy and Warm Water Immersion for Mild Hypothermia Rewarming

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Objective.—The purpose of the study was to determine the effectiveness of Fluidotherapy rewarming through the distal extremities for mildly hypothermic, vigorously shivering subjects. Fluidotherapy is a dry heat modality in which cellulose particles are suspended by warm air circulation.

Methods.—Seven subjects (2 female) were cooled on 3 occasions in 8°C water for 60 minutes, or to a core temperature of 35°C. They were then dried and rewarmed in a seated position by 1) shivering only; 2) Fluidotherapy applied to the distal extremities (46 ± 1°C, mean ± SD); or 3) water immersion of the distal extremities (44 ± 1°C). The order of rewarming followed a balanced design. Esophageal temperature, skin temperature, heart rate, oxygen consumption, and heat flux were measured.

Results.—The warm water produced the highest rewarming rate, $6.1°C \cdot h^{-1}$, 95% CI: 5.3–6.9, compared with Fluidotherapy, $2.2°C \cdot h^{-1}$, 95% CI: 1.4–3.0, and shivering only, $2.0°C \cdot h^{-1}$, 95% CI: 1.2–2.8. The Fluidotherapy and warm water conditions increased skin temperature and inhibited shivering heat production, thus reducing metabolic heat production (166 ± 42 W and 181 ± 45 W, respectively), compared with shivering only (322 ± 142 W). Warm water provided a significantly higher net heat gain (398.0 ± 52 W) than shivering only (288.4 ± 115 W).

Conclusions.—Fluidotherapy was not as effective as warm water for rewarming mildly hypothermic subjects. Although Fluidotherapy is more portable and technically simpler, it provides a lower rate of rewarming that is similar to shivering only. It does help decrease shivering heat production, lowering energy expenditure and cardiac work, and could be considered in a hospital setting, if convenient.

Key words: shivering heat production, thermal core, effective perfused mass, afterdrop, hospital treatment

Introduction

Many wilderness and adventure activities present the risk of cold exposure and accidental hypothermia. In the United States, approximately 1500 hypothermic patients visit an emergency department (ED) each year.[1] Patients with mild to moderate hypothermia are generally warmed externally, namely, with warm water bottles "in the field"[2] or forced air warming "in the ED."[3] These methods generally increase skin temperature and reduce shivering heat production, resulting in afterdrop and rewarming rates similar to those of shivering (control) protocols; shivering inhibition reduces metabolic energy use, cardiac work, and discomfort.[3]

Whole body warm water immersion is contraindicated as it increases the risk of cardiovascular collapse.[4] However, immersing only the distal extremities in 45°C water safely decreased afterdrop and almost tripled the core rewarming rate to ($9.9°C \cdot h^{-1}$) compared with other external methods.[5] Limitations of this method include water spillage, specialized temperature control equipment, space requirements, and a fixed location.

Fluidotherapy, a common physiotherapy heating modality for distal extremities, is a potential alternate distal extremity rewarming method. This modality consists of a warming chamber with openings for distal arms

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and legs.[6] Cellulose particles, which form a fluidized bed, are circulated around the extremities by hot air. Fluidotherapy (48°C–49°C) provided three times greater heat transfer to copper bars,[6] and warmed muscle tissue by 20% to 50% more,[7] than warm water (39°C–41°C) or wax baths (52°C–55°C). This increased heat transfer may result from tolerance of higher temperatures of the fluidized bed compared with warm water, convective air movement, and high thermal conductance of cellulose particles.[6,7] Higher temperature tolerance occurs because the cellulose particles overstimulate skin thermoreceptors and mechanoreceptors, consequently decreasing pain sensitivity.[6] Moreover, dry heat minimizes thermal irritation at high temperatures.[6] This method also provides more heat than traditional forced air warming[3] owing to a combination of higher air temperature (~5°C) and thermal conductance of cellulose particles. Potential practical benefits of Fluidotherapy (compared with distal limb immersion) are that it is commercially available, technically simple, programmable, requires less space, is portable, and avoids water spillage.

The purpose of this study was to evaluate Fluidotherapy warming of all distal extremities in mildly hypothermic subjects. We hypothesized that Fluidotherapy (50°C) would provide more heat, reduce shivering and afterdrop, and increase core rewarming compared with extremity immersion in warm water (at 45°C) and shivering only.

Methods

SUBJECTS

Physically active volunteers were studied after screening for any medical conditions and giving written informed consent. The Biomedical Research Ethics Board at the University of Manitoba approved the protocol.

INSTRUMENTATION

A single-channel electrocardiogram and heart rate were monitored continuously, and core temperature was measured by a thermocouple inserted into the esophagus (T_{es}) to the level of the heart.[8] Skin temperature (T_{skin} [°C]) and cutaneous heat flux (HF [$W \cdot m^{-2}$]) were measured at 12 sites with thermal flux transducers (Concept Engineering Old Saybrook, CT). Sites were forehead, anterior and posterior torso, upper arm, proximal and distal forearm, hand, anterior and posterior thigh, and proximal and distal lower leg and foot. Positive values indicate heat loss from the skin. Oxygen consumption (V_{O_2} [$L \cdot min^{-1}$]) and minute ventilation (V_E [$L \cdot min^{-1}$]) were determined with an open-circuit method (Vmax 229, SensorMedics Yorba Linda, CA).

REWARMING METHODS

Because subjects were seated in a head-down position during Fluidotherapy and water rewarming, they also assumed this position in the shivering condition to eliminate any possible effects of posture.

For the shivering only (control) rewarming method, after being seated, subjects leaned forward, resting their head on a head support, and were then covered with a sleeping bag. In this condition, the subject rewarmed spontaneously by endogenous shivering thermogenesis.

For the Fluidotherapy rewarming method, a chamber (model 115D, DJO Canada, Mississauga, Ontario) 86 cm long, 47 cm wide, and 84 cm high was used. New sleeves were created for the top portals of the chamber to allow insertion of all four distal extremities (ie, lower legs up to the knee and forearms up to the elbow). The unit was preheated to 45°C at 35% air speed. After limb insertion, the unit was then turned on at 45°C and 100% air speed. The subjects were then covered with a sleeping bag. Unit temperature was adjusted during the rewarming period based on the subject's tolerance (maximum, 50°C) (Figure 1).

For the warm water method, the goal was to maintain water temperature at 45 ± 1°C; this would have the effect of decreasing the temperature advantage of Fluidotherapy, but we wanted to test both conditions at their maximum tolerable temperature and, therefore, rewarming effectiveness. After immersion, subjects were hoisted into the warm water tank and positioned with lower legs immersed to knee level. They then leaned forward resting their head on the front support, immersing their forearms up to the level of elbow (ie, same level as Fluidotherapy immersion), and were covered with a sleeping bag (Figure 1).

PROTOCOL

Each subject was cooled on three different occasions separated by at least 48 hours, at the same time of day. Both female subjects were consistently studied in the follicular phase. After 10 minutes of baseline measurements, subjects were immersed up to the sternal notch in an approximately 21°C stirred water bath. Water temperature was then lowered to 8°C over 10 minutes by the addition of ice. Subjects remained in the water until either T_{es} reached 35°C or 60 minutes elapsed. Subjects were towel dried and then rewarmed by one of the three treatment methods. The order of rewarming methods was randomly chosen and followed a balanced design. Treatment continued for 60 minutes or until T_{es} rose to 37°C, followed by warm water immersion (40°C–42°C) until the T_{es} rose to 37°C (if necessary) or the subject wished to exit.