Accidental Hypothermia

Gordon G. Giesbrecht, Ph.D., Professor
Health Leisure and Human Performance Research Institute
University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2N2

Learning Objectives:

1) Understand the different effects of cold exposure;

2) Diagnosis and treatment of hypothermia in the field or hospital.

Introduction

The primary effect of body cooling is a decrease in tissue metabolism and inhibition of neural control and transmission. However, in the intact conscious condition, the secondary responses to skin cooling predominate. Therefore, sudden cooling initiates shivering thermogenesis, and increased metabolism (VO_2), ventilation (V_E), heart rate (HR), cardiac output (CO) and mean arterial pressure (MAP). The primary effects of cooling can be seen during anesthesia or at lower core temperatures (i.e., <30°C) when shivering ceases and VO_2, HR, MAP, and CO decrease with core temperature while hematocrit and total peripheral resistance increase.

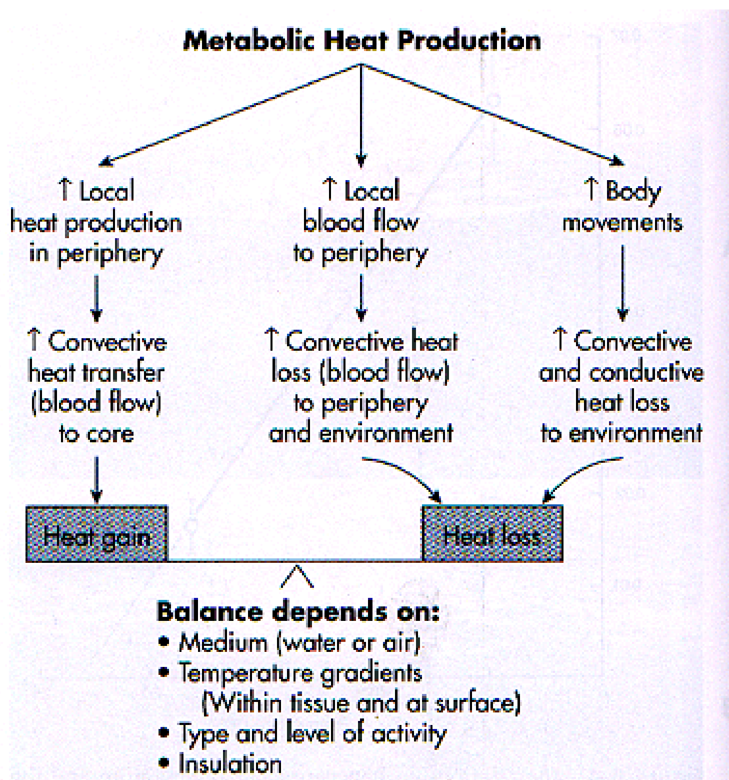
Decrease in core temperature

The factors that affect the rate of body cooling include: the medium of exposure (i.e. water or air); ambient temperature; redistribution of blood flow between the body core and periphery; insulation of superficial layers (i.e., fat and clothing); and endogenous heat production (i.e., exercise and shivering).

One important protective factor is shivering; an involuntary function where increased heat production is generated in an effort to prevent body core cooling. Shivering intensity depends on: ambient temperature; body composition (shivering intensity at a given ambient temperature is lower with greater skinfold thickness); and the rate of change of skin and core temperature.

The effectiveness of shivering depends on the balance between many factors (Figure 1). Generally, local heat production in peripheral muscles is transferred to the core via venous return. On the other hand shivering may increase heat loss through increased blood flow to the periphery. However, in almost all circumstances this balance favors heat gain and ultimate protection against cooling.

Figure 2 indicates that shivering heat production (indicated by VO_2) can maintain core temperature (T_{es}) in cold air (A) and

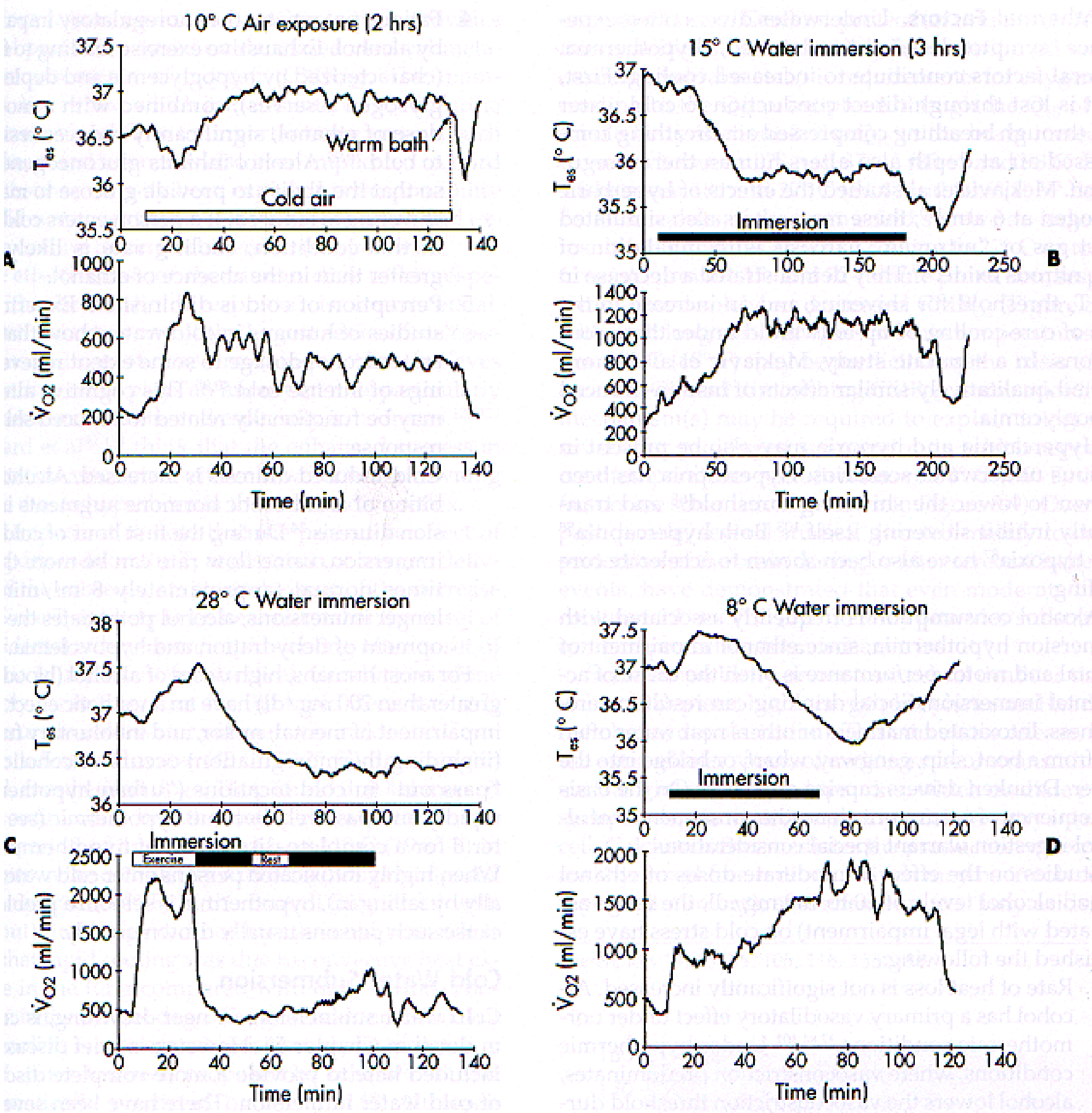


Factors influencing total thermal balance during increases in metabolic heat production (e.g., voluntary exercise and involuntary shivering).

can arrest the fall in core temperature in warm and cool water (B and C). However, if the cold stress is great enough (D) cooling may be retarded but will continue. The power of shivering is especially important in the consideration of classification of hypothermia and eventual treatment because this valuable heat source is efficient at rewarming the core post-cooling.

Post-cooling

Following cooling the body core continues to drop. This afterdrop is a function of a dynamic combination of mechanisms. Two factors occur at the local level (i.e., within each body cylinder; upper leg, lower leg etc.). First, conductive cooling occurs based on temperature gradients that depend on the extent of the cold exposure. These gradients mainly promote radial surface-to-center cooling (1) although some longitudinal distal-to-proximal gradients may also exist (3). Second, local tissue heat production will, to some extent, offset the physical effect of conductive cooling. Finally, local tissue blood flow will be affected by the temperature and flow rate of incoming blood. Although conductive cooling is



Effectiveness of shivering heat production in preventing onset of hypothermia during exposure to A, 10° C (50° F) air; B, 15° C (59° F) water; C, 28° C (82.4° F) water; and D, 8° C (46.4° F) water. Tes, esophageal temperature.

indisputable, the only way that cooling in any body cylinder (other than the trunk) can affect core temperature is by convective transfer via blood flow from these distal areas to the heart. If peripheral blood flow is similar before and after cooling, the conductive component of afterdrop predominates. If however, peripheral vasodilation occurs, the increased blood flow will cause a redistribution of heat from the core to the periphery much like occurs immediately following induction of anesthesia (4). The contribution of the convective mechanism will be proportional to the relative increase in peripheral blood flow. This also has important implications in the handling and treatment of victims post-cooling. Several clinical case reports indicate afterdrop values ranging between 1.3 to 6.4 °C (2).

There are many clinical examples of victims being removed from a cold exposure in an apparently stable and conscious condition only to degenerate from one level of hypothermia to another. This can result in "rewarming shock" or "post-rescue collapse" with symptoms ranging from syncope to ventricular fibrillation and cardiac arrest. There are 3 probable factors that generally lead to rewarming shock: 1) hypovolemia, hypotension and decreased brain blood flow; 2 humoral factors such as an increase in metabolic byproducts and catecholamines); and 3) a significant afterdrop in core temperature. It is likely that the afterdrop in core temperature is an important factor because decreased myocardial temperature precipitates ventricular fibrillation or asystole. Also, a secondary effect of cooling the myocardium may be hypersensitization of the heart to humoral factors (i.e., catecholamines and metabolic byproducts) and mechanical stimulation (i.e., intubation). The importance of the phenomenon is shown in a review of 21 patients with initial core temperatures between 14 and 28 °C, initial functional cardiac rhythms and who were eventually treated with cardiopulmonary. Five of the 21 patients developed ventricular fibrillation or asystole after rescue and commencement of treatment (2).

Classification for Level of Hypothermia

Core Temperature	Thermoregulatory Status	Signs and Symptoms	Classification
37 °C			Normal
<37°C		- Cold Sensation - Shivering	
35-32°C	Control and Responses Fully Active	Physical Impairment - Fine Motor - Gross Motor Mental Impairment - Complex - Simple	Mild
32-28°C	Responses Attenuated/ Extinguished	~30°C - Shivering Stops - Loss of Consciousness	Moderate
<28°C	Responses Absent	- Rigidity - Vital Signs Reduced or Absent - Risk of VF/CA (Rough Handling)	Severe
<25°C		- Spontaneous Ventricular Fibrillation - Cardiac Arrest	

Criteria for classification of hypothermia.

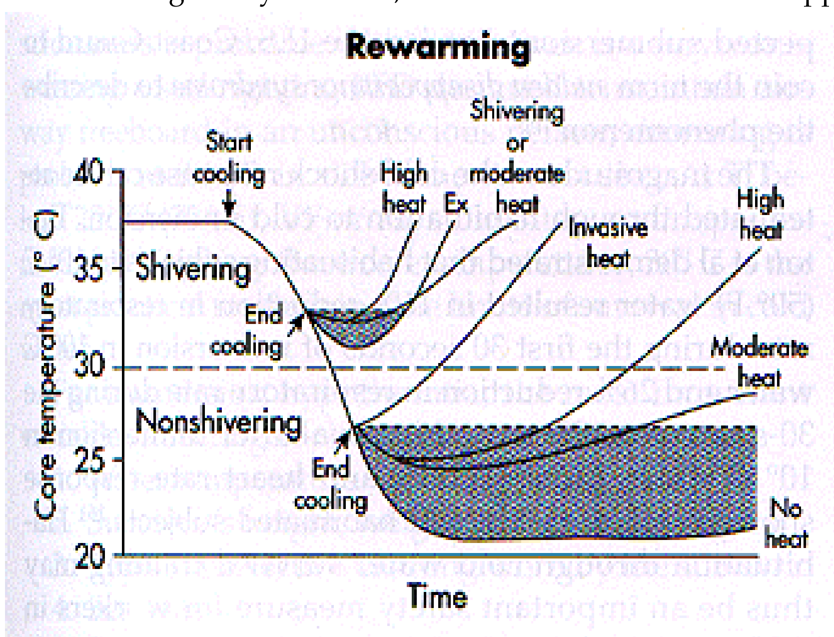
Diagnosis

There are several classification systems for hypothermia based on core temperature. We use a simple classification system (Figure 3) which is based on general functional characteristics: Mild hypothermia [core temperature (T_{CO}): 35-32°C, conscious, vigorous shivering as thermoregulatory mechanisms are fully functional, and locomotion]; Moderate hypothermia (T_{CO}: 32-28°C, altered consciousness, shivering diminishing as thermoregulatory mechanisms are becoming less effective, cardiac dysrhythmias); and Severe hypothermia (T_{CO} < 28°C, unconscious, shivering has ceased, ventricular fibrillation, asystole, ultimately death). Core temperature measurements are, at best, difficult in the field. Both diagnosis and treatment can be effectively based on the functional characteristics listed above.

Rewarming

Treatment may depend on whether the hypothermia is simply a primary result of excessive heat loss in individuals with otherwise normal thermoregulatory function, or secondary to impaired thermoregulation from metabolic disease, old age or alcohol and drug abuse. It may also depend on whether the onset of hypothermia was acute (minutes to a few hours) or chronic (several hours to days). The main priorities for treatment are to arrest the fall in core temperature, and maximize a safe rewarming rate while maintaining the stability of the cardiovascular system and correcting metabolic imbalances. Rewarming methods can be classified according to: a) the source of heat (i.e., exogenous or endogenous); b) where the heat is applied (i.e., core or shell, internal or external, central or peripheral); c) whether it is invasive or noninvasive; d) the amount of heat (moderate or high); or e) whether heat is even applied (active or passive).

For our purposes the following rewarming classifications will be used (see Table 1). Endogenous Rewarming includes shivering and exercise, and clarifies that there is active heat production occurring. Exogenous External Rewarming differentiates between moderate and high sources of heat that are applied to the body



Schematic illustration of the effectiveness of various rewarming techniques under shivering and nonshivering hypothermic conditions. Dashed line (at 30° C) indicates approximate core temperature at which shivering is spontaneously abolished. *Ex*, External rewarming.

surface and Exogenous Internal Rewarming includes noninvasive and invasive methods for application of heat to the core.

In conclusion, the following general principles apply to treatment selection (see Figure 4). If vigorous shivering is present, Endogenous Rewarming should be maximized by drying the patient and providing insulation and a vapor barrier. Exogenous External Rewarming provides little afterdrop protection or rewarming advantage unless either a large amount of heat is provided, or core temperature is in the range of moderate hypothermia and shivering is waning.

Table 1. Rewarming Classifications*

Endogenous Rewarming
Basal metabolism
Shivering
Exercise

Exogenous External Rewarming
a) Moderate sources of heat:
Forced air warming
Heating pads
Charcoal heaters
Human body
Hot water bottles (other objects)
Warmed blankets (electric, water perfused)
Piped suits
Radiant heat
Hibler technique (hot water soaked sheets)
b) High sources of heat
Forced air warming
Warm water immersion

Exogenous Internal Rewarming
a) Noninvasive
Hot food and drink
Inhalation of heated saturated air/oxygen
b) Invasive
Warm IV fluids
Arteriovenous fistula
Lavage (peritoneal, gastric, thoracic, bladder)
Cardiopulmonary bypass

* Regardless of the level of hypothermia or the rewarming method to be used, patients should first be removed from the cold exposure as gently as possible, dried and provided with as much insulation as practical.

If the patient is severely hypothermic, rapid (but gentle) evacuated is required. In pre-hospital conditions, where possible, Exogenous External Rewarming should be provided for each level of hypothermia with a target rewarming rate between 1 and 2 °C/hr. Warming can cease once core temperature reaches 35°C (if measurements are possible). Finally, treatment selection depends on location. For example treatment in nursing stations is limited to Exogenous External Rewarming techniques, in addition to warm IV fluid infusion and heated humidified air/oxygen. In 1° and 2° hospitals, more invasive Exogenous Internal Rewarming techniques like peritoneal lavage and continuous arteriovenous rewarming can be performed. Cardiopulmonary bypass is the most effective rewarming method for severe hypothermia but is only available in 3° hospitals.

References

1. **Bristow, G. K., D. I. Sessler, and G. G. Giesbrecht**. Leg temperature and heat content in humans during immersion hypothermia and rewarming. *Aviat. Space Environ. Med.* 65: 220-226, 1994.

2. **Giesbrecht, G. G.** Cold stress, near drowning and accidental hypotherima: A review. *Aviat. Space and Environ. Med.* 71:733-52,2000.

3. **Saltin, B., A. P. Gagge, and J. A. J. Stolwijk**. Muscle temperature during submaximal exercise in man. *J. Appl. Physiol*. 25: 679-688, 1968.

4. **Sessler, D. I., J. McGuire, A. Moayeri, and J. Hynson**. Isoflurane-induced vasodilation minimally increases cutaneous heat loss. *ANESTHESIOLOGY*. 74: 226-232, 1991.