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Author:
Angela F. Gardner, MD, FACEP
Assistant Professor, Department of Surgery/Emergency Medicine, University of Texas Medical Branch, Galveston.

Peer Reviewer:
Jonathan Glauser, MD, Chairman, Emergency Department, Cleveland Clinic, Cleveland, OH.

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Accidental Hypothermia

Introduction

Hypothermia has been recorded throughout history. Galen, personal physician to Marcus Aurelius, wrote in his treatise "Hygiene" that newborns should be wrapped in swaddling clothes because, "it is necessarily going to come in contact with cold and heat."[1] Baron Dominique-Jean Larrey, who served as Napoleon's field surgeon during the disastrous Russian campaign of 1812, observed that a frozen limb produced almost no pain during amputation. He reportedly performed more than 300 extremity amputations using "cryoanesthesia" during the retreat along the Berezina River in November 1812.[2] He also noted that frozen men rewarmed near a fire fared worse than those further from the heat source. He is credited with identifying afterdrop; that, is when a person is warmed externally, the vasodilatation will cause cold and acidic blood from the extremities to lower the core body temperature.

Military history provides other sobering examples of cold-related injuries and fatalities. Hitler lost 23% of his forces during the winter of 1941 with temperatures –30°C (–22°F). Bomber crews in World War II reported high altitude frostbite. U-boat captains and pilots suffered injuries and death in the cold waters of the North Atlantic. German and American losses due to cold injury were approximately 100,000 and 90,000, respectively.[3] More than 10% of American casualties during the Korean War were due to hypothermia.

Hypothermia in modern times is largely an infirmity of adventurous outdoor enthusiasts or the poverty-stricken homeless. As the economic climate worsens, there may be growing numbers of homeless people risking exposure in both urban and rural environments. This paper reviews recognition, evaluation, and treatment of accidental hypothermia. This paper does not deal in detail with the other types of cold injury such as frostbite.

Epidemiology

In the United States, there were an estimated 15,574 emergency department (ED) visits for hypothermia and other cold-related injuries between 1995 and 2004.[4] Many of those visits required some period of hospitalization in the intensive care unit. More than 650 deaths each year in the United States are attributed to hypothermia.[5] Factors contributing to the incidence of hypothermia include extremes of age, concurrent or chronic illness, alcoholism, substance abuse, and homelessness. A significant percentage of cases involve two or more of the above factors. Hypothermia may account for more deaths than are reported, especially among the elderly, because it may go unrecognized as a co-morbid condition.

Mortality rates in the United States vary from 4.64 per 100,000 persons in Alaska to 0.49 per 100,000 in some southern states.[6] In fact, hypothermia is seen in milder climates where the temperature changes rapidly, such as North Carolina, South Carolina, and Arizona.[7] The highest death rates from hypothermia are seen in Alaska, New Mexico, North Dakota, and Montana.[6] Males and females are equally susceptible to hypothermia, but among civilian populations, most cold-

Executive Summary

- **Accidental hypothermia is defined as a core body temperature of < 35°C (95°F).**
- **Patients with severe hypothermia may appear to be dead, with fixed dilated pupils and severe bradycardia. However, some patients who are very cold can be successfully resuscitated.**
- **Forms of rewarming include active and passive, external and internal. The most aggressive, cardiopulmonary bypass, is reserved for patients who are severely hypothermic, are in arrest, or are hemodynamically very unstable.**
- **Patients may become more hypothermic during initial rewarming because of afterdrop.**
- **After resuscitation, patients with significant hypothermia should be admitted to the ICU.**

related deaths are males.[8] In fact, death rates among men are 3 times higher than women in all age groups except children younger than 15 years.[9] Women have an increased layer of subcutaneous fat, allowing them to maintain their body temperature longer.[10] Hypothermia equally affects all racial groups.

Approximately half of all reported hypothermia deaths are in the elderly population. Several factors contribute to this finding. Physiologically, the human body loses the capacity to adequately thermoregulate with age. In addition, those older than 65 years are more likely to have chronic conditions such as congestive heart failure or diabetes, which increase the risk of hypothermia.[6] Also, elderly patients may live in older homes that are more difficult to heat or may not be able to afford the energy costs of adequate heating. Thus, elderly patients may fall victim to hypothermia without ever leaving their homes.[11]

Likewise, children are more susceptible to hypothermia.[10] This is likely due to their high body surface area:body mass ratio as well as their inability to verbalize cold at very young ages.

Definitions

Hypothermia traditionally is defined as a core body temperature less than 35°C (95°F). Humans are endothermic (endo: within) and homeothermic (homos: the same; thermos: heat) mammals, meaning they maintain a near-constant average core temperature despite environmental extremes, largely through metabolic processes.[12] Hypothermia could be described best as the temperature at which the body loses the ability to adequately generate enough heat to maintain its natural functions.

Accidental hypothermia refers to the unintentional decline in core temperature below 35°C (95°F). Therapeutic hypothermia in the clinical environment has been used to preserve the brain and other organs during cardiopulmonary bypass, traumatic brain injury, and after cardiac arrest.

Primary hypothermia occurs because of unintentional exposure of an otherwise healthy person to a cold environment. The difference between ambient temperature and core temperature does not have to be pronounced, and hypothermia has been reported in environments above 0°C (32°F).

Secondary hypothermia occurs when a disease state interferes with the thermoregulatory processes. Many factors contribute to susceptibility to cold, including age, intoxication, state of hydration, nutrition, and physical impairment of behavioral responses. Some examples of secondary hypothermia are listed in Table 1. It is possible for primary and secondary hypothermia to coexist.

Hypothermia can be categorized as follows:

- Mild hypothermia: 32-35°C (90-95°F);
- Moderate hypothermia: 28-32°C (82-90°F);
- Severe hypothermia: below 28°C (82°F).

This manuscript will use these three categories. In addition to mild, moderate, and severe hypothermia, some experts refer to profound hypothermia, the lowest temperatures from which human recovery is possible.[13]

Cold stress refers to any degree of environmental cold that causes the physiological thermoregulatory mechanisms to be activated.[14]

Immersion hypothermia refers to the particular event in which a victim has become hypothermic because of

Table 1: Secondary Causes of Hypothermia

Medications
• Phenothiazines
• Barbiturates
• Neuromuscular blocking agents
Exposures
• Organophosphates
• Heroin
• Carbon monoxide
• Alcohol
Endocrine
• Hypopituitary
• Hypoadrenal
• Hypothyroid
Other
• Sepsis
• Cancer
• Pancreatitis
• Uremia
• Starvation
• Anorexia nervosa

Table 2: Commonly Worn Clothing in Increasing Effectiveness to Prevent Hypothermia

- Shirt, pants, socks, and shoes
- Shirt, pants, socks, shoes, jacket
- Windproof, waterproof jogging suit, socks, shoes
- Fleece shirt and pants, socks, shoes
- Jacket, thermal long underwear, socks, shoes
- Ski jacket and pants, thermal long underwear, sweater, goggles, socks, boots
- Down-filled cold weather parka with hood, ski pants, thermal long underwear, thick socks, and boots
- Expedition suit

sudden immersion in cold water. Death from hypothermia in icy waters occurs within 20-30 minutes, although there are many reports of individuals, most often children, who survive after longer submersion in icy waters. Death from drowning occurs in a shorter period. All victims of immersion in cold water should be transported to a medical facility and assumed to have a lowered body temperature.

Thermoregulation

The human body maintains a physiologic heat balance by generating internal heat to balance heat lost to the environment. This physiologic heat balance is the result of many variables, including age, conditioning, nutritional status, hydration, body size, and the ability to perform behavioral adaptations to cold stimuli. In general, heat flows from a warmer object to a colder object. In most circumstances, the body is warmer than the environment, and heat flows out of the body.

The body loses heat to the surrounding environment through convection, conduction, evaporation, and radiation. In temperate climates, 55-60% of heat loss occurs through radiation, with the remainder lost through evaporation. Most clothing of currently available materials does little to reduce these forms of heat loss. (*See Table 2.*) By contrast, convection (wind) is the major source of heat loss in a cold terrestrial environment. Conduction is the major source of heat loss in cold-water immersion. Both convection and conduction losses can be delayed by appropriate use of available clothing materials.

Radiation. Radiation is the direct absorption or emission of heat energy, and is poorly understood by many. Radiation from the sun (largely infrared) is absorbed by solid objects, including the human body. Radiant energy allows spring skiers to comfortably ski in shirtsleeves, despite an air temperature of 0°C (32°F) that would otherwise be uncomfortable. In a calm 21°C (70°F) environment, a clothed, sedentary person loses about 60% of body heat through radiation.[12]

Convection. Convection occurs when the warm layer of heat next to the body is lost by the movement of air. The amount of heat lost by convection is determined by the temperature difference between the air (or water) and the body surface, and by the speed at which the air is moving. The greater the temperature difference, the larger the heat loss.

Even more significant than temperature difference is the ability of wind to remove large quantities of heat. The amount of heat lost in a wind is a square of the velocity, not a proportion of the velocity. In other words, a wind moving 10 miles per hour removes four times as much heat as a wind moving 5 miles an hour, not twice as much. The increase becomes negligible at speeds greater than 40 miles per hour because the wind does not stay in contact with the skin long enough to increase further.

Paul Allen Siple and Charles Passel developed the concept of wind chill while working in Antarctica prior to World War II. They made their observations using a suspended water bottle and observed its cooling under different weather conditions. In 2001 the wind chill was changed to a new system based on the cooling effect on a human face. Wind chill is the term used for the cooling effect of wind in a cold environment.

Convective cooling in water is greater than in air. For this reason, most people submerged in cold water with minimal insulation lose more heat by trying to swim than would be lost by remaining still.

Conduction. Conduction is the direct transfer of heat from one surface to another. Air conducts heat poorly and may be a good insulator when still. Water conducts heat well, with approximately 25 times greater conductivity than air. The greater the percentage of body immersed, the more rapid the onset of hypothermia.[10] Stone and ice are good conductors, and the body may lose significant amounts of heat when in contact with these substances.

Conduction can be used to advantage for warming. A body in contact with a hot water bottle, heating pad, or hot bath will gain heat by conduction.

Evaporation. Evaporation is the heat lost when liquids are converted to gas. The evaporation of water cools the body 0.6 kcal per gram. For a sedentary person in a temperate environment, this equals about 300 kcal, or 15% of the daily dietary intake.[12] Even without the heavy physical exertion that produces obvious sweating, the body produces a constant flow of fluid that lubricates the skin. This process, known as insensible loss, accounts for about two-thirds of the evaporative losses in a thermoneutral environment. Insensible loss continues in a cold climate.

Exercise produces obvious sweat and increases the heat loss. This also occurs in the cold environment with heat generated by heavy exercise.

The remainder of evaporative heat loss occurs in the airways (insensible water loss). When air is inhaled, enough water is added by the upper airway mucosa to bring the relative humidity of the inhaled air to 100%. When cold air is inhaled, the body

Table 3: Physiologic Changes Seen with Hypothermia

	Body Temperature	Physical Changes
Mild	35°C	Maximal shivering
	34°C	Amnesia, behavioral changes
	33°C	Ataxia
Moderate	32°C	Obtunded
	31°C	Shivering stops, dilated pupils
	30°C	Cardiac arrhythmias
	29°C	Coma
Severe	28°C	Ventricular fibrillation risk
	27°C	Loss of voluntary movement, reflexes
	26°C	No response to pain
	24°C	Hypotension, bradycardia
	23°C	Loss of corneal reflex
	19°C	EEG flat
	18°C	Asystole
	13.7°C	Lowest survived temperature

also raises the temperature of the inhaled air, which drops the relative humidity of the inhaled air by 1-2%. The resultant evaporative losses exceed those of the more temperate environment.

The human body maintains a steady core temperature in the face of heat loss through a central mechanism involving the preoptic anterior hypothalamus. In general, cold stimuli are transmitted via lateral spinothalamic tracts to the relevant hypothalamic nuclei. The hypothalamus responds to the stimuli by adjusting heat production and heat loss.

Heat production is accomplished by shivering and by non-shivering mechanisms. Shivering, which is centrally controlled, produces an increase in muscle tone, an increase in metabolic rate, and an increase in heat production. Shivering is more efficient at heat production than voluntary muscle contractions of the extremities.[13] Even moderate hypothermia decreases the metabolic response to cold, and at a body temperature of about 30°C (86.0°F), the shivering response is lost.

The hypothalamus also regulates nonshivering responses to cold stimuli, increasing thermogenesis via thyroxine and epinephrine. Both shivering and nonshivering responses increase oxygen demands, possibly impairing the body's response to hypothermia in a low-oxygen environment.

Heat conservation is accomplished directly by vasoconstriction of the peripheral blood vessels, mediated by the central nervous system and by direct action of the cold on the vessels of the skin. The head is the only portion of the body minimally affected by vasoconstriction and continues to lose heat linearly between 32°C and –20°C. The resting heat loss from the head may equal half of the total heat production at –4°C.[15]

While some acclimatization occurs after chronic exposure to cold, it is not as efficient. Humans vasoconstrict their peripheral circulation when exposed to cold. However, periodically the body increases blood flow to a cold extremity (primarily the fingers), which helps delay frostbite.[16] This cold-induced vasodilatation (CIVD) becomes less pronounced in individuals chronically exposed to cold. In addition, those chronically exposed to cold will have an exaggerated shiver response.[10]

Pathophysiology

The effects of cold on the body are summarized in Table 3. These are approximate temperatures, and an individual may respond differently.

Cardiovascular. Many of the cardiovascular responses to hypothermia remain poorly understood. Autonomic nervous system stimulation causes an initial tachycardia and peripheral vasoconstriction. Following the initial tachycardia, there is a linear decline in heart rate that approaches 50% of normal at 28°C (82.4°F). The bradycardia associated with hypothermia is resistant to atropine, since it is the result of decreased spontaneous depolarization of the pacemaker cells. A relative tachycardia at a core temperature that should produce bradycardia suggests the presence of an occult process such as trauma, hypoglycemia, or drug ingestion. Hypothermia progressively decreases the mean arterial pressure and cardiac index, and this may persist despite rewarming.

The J wave (Osborn wave or hypothermic bump) is most commonly seen in leads II and V6 and may occur at any temperature below 32.2°C (90°F.) As the core temperature falls below 25°C (77°F), J waves are found in the anterior and lateral precordial leads. Located at the junction of the QRS complex and the ST segment, the J wave amplitude increases with the progressive decline in temperature. There is no consensus over the mechanism of the generation of J waves. It has been suggested it is due to acidosis or a neurogenic factor of injury current,[17] but neither of these has been proven. Contrary to popular belief, while the J wave may be highly suggestive of hypothermia, it is *not* pathognomonic. J waves also are found with central nervous system lesions, focal cardiac ischemia, Chagas disease, Brugada syndrome, sepsis, and in young, healthy persons.[17,18] Further, the presence or absence of J waves is not prognostic.[17,19]

With deepening hypothermia, the P wave loses height and there is prolongation of the PR, QRS, and QT intervals, in that order.[17] There also may be T wave changes that mimic myocardial ischemia.[17]

Below 32.2°C (90°F), atrial and ventricular dysrhythmias occur. The loss of height of the P wave may be misinterpreted as atrial fibrillation,[17] but atrial fibrillation is common. Hypothermia-induced ventricular fib-

Table 4: Some Conditions that Predispose to Hypothermia

Endocrine	Hypopituitary, hypoadrenal, hypothyroid, diabetes
Nutrition	Hypoglycemia, starvation, excessive exertion, anorexia nervosa
Medications	Vasodilators, overdose of sedatives or psychotropic medications
Skin	Burns, psoriasis, ichthyosis, exfoliative dermatitis
Neurological	Neuropathies, acute spinal cord injuries, trauma, stroke, subarachnoid hemorrhage, hypothalamic dysfunction, Parkinson's, tumor, multiple sclerosis
Other	Sepsis, pancreatitis, cancer, uremia, vascular insufficiency, extremes of age

rillation and asystole occur spontaneously below 25°C (77°F), possibly in response to the slowing conduction along all pathways as the heart cools. The heart becomes quite irritable at temperatures below 30°C. Ventricular fibrillation may result from therapeutic manipulation, hypovolemia, rough handling, sudden vertical positioning, or metabolic stress from the rewarming process.[19]

Respiratory. Exposure to cold causes stimulation of the respiratory drive, followed by depression of the minute volume as the metabolic rate declines. At body temperatures below 30°C (86°F), the respiratory rate falls to 5-10 breaths per minute and eventually stops when brainstem neurocontrol of ventilation fails. Carbon dioxide production decreases 50% for every decrease of 8°C in temperature.[20,21]

Non-cardiogenic pulmonary edema may occur in some patients, particularly the elderly and those with prolonged exposure to cold.[5]

Renal. The initial vasoconstriction caused by hypothermia causes a relative central hypervolemia. In response, the kidneys produce a "cold diuresis," which increases the urinary output but does not clear nitrogenous wastes as efficiently as under thermoneutral conditions. Cold diuresis is felt to be multifactorial, resulting from inhibition of antidiuretic hormone (ADH) release as well as from vasoconstriction. Following the cold diuresis, cardiac output decreases and vascular tone increases, decreasing the glomerular filtration rate. Eventually, acute renal failure occurs.

Central Nervous System (CNS). One of the earliest signs of hypothermia is a change in behavior or personality. Unfortunately, the hypothermia victim, subject to the progressive depression of the central nervous system by the cold, is the least likely to notice early signs of CNS involvement. Fine motor skills decline, manifested as difficulty with zippers, buttons, etc., followed by dysarthria and decline in gross motor skills. Cerebrovascular autoregulation preferentially redistributes blood flow to the brain until the core temperature falls below 25°C (77°F.) There is great individual variability in CNS effects of hypothermia, both centrally and peripherally. A mnemonic for remembering the onset of CNS effects is:

- Mumbles
- Grumbles
- Fumbles
- Stumbles
- Tumbles.

One of the more unusual manifestations of hypothermia is paradoxical undressing. The victim may be found partially or totally unclothed despite severe cold. Historically this has been described in prehistoric man[22] and in the Antarctic expedition headed by Robert Scott.[23] Some 25-50% of individuals with severe hypothermia discard their clothes.[24] Some believe this behavior is a result of the fatigue of vasoconstriction near the end of life. The warm blood of the body's core then rushes to the cold extremities, giving the sensation of intense warmth.[24]

Recognition and Diagnosis

It is intuitively obvious that a hiker stranded on a mountaintop in winter for a prolonged period is at risk for hypothermia. Less obvious is the elderly cardiac patient without adequate heating in the home who presents to the emergency department with a complaint of altered mental status. The cornerstones for diagnosis of hypothermia are:

- Suspect hypothermia;
- Take a core temperature.

Suspect Hypothermia. A number of conditions predispose patients to hypothermia. (*See Table 4.*) Consider hypothermia as a possible diagnosis under these circumstances:

- The patient has a recent recreational exposure to a cold environment. Poorly conditioned persons present a greater risk of hypothermia.
- The patient has an underlying disease and an exposure to cold. Hypothyroidism, sepsis, pneumonia, stroke, hyper- or hypoglycemia, pancreatitis, and uremia patients represent an increased risk.
- The patient is a trauma victim. Concurrent hypovolemia, hypotension, or head injury may further decrease the stability of the thermoregulatory system. More than 50% of trauma patients are hypothermic at some time during their care.[5] Mortality is higher in patients who are hypothermic.[5]
- The patient has inadequate clothing for the ambient temperature. Individuals who are indigent or homeless may be unable to procure adequate clothing. Patients with underlying mental or behavioral disorders may suffer from errors in judgment about appropriate clothing for the environment.
- The patient is intoxicated. Alcohol, drugs, and sedative/hypnotics reduce the patient's ability to deploy behavioral responses to com-

bat the cold. In some studies, nearly 70% of hypothermic patients are intoxicated.[25] In New Mexico, the Native American population is 30 times more likely to die from hypothermia, and nearly 90% of these test positive for alcohol.[26] Some drugs, e.g. phenothiazines, inhibit the body's ability to shiver.

• The patient is very young or very old. Patients in the extremes of age are unable to maintain thermoneutrality as well as healthy adults.

• The patient has a long pre-hospital transport time in cold weather.[27] Patients receiving cold crystalloids, transported in unheated ambulances, and undressed for emergency evaluation may suffer from hypothermia.

• The patient has a skin condition that exposes large surface areas to fluid loss (burns, ichthyosis, psoriasis, and exfoliative dermatitis).

Take a Core Temperature. A rectal temperature is the most clinically useful in the emergency department, but has limitations in that it may not accurately reflect heart or brain temperature. Rectal temperatures may be influenced by the temperature of the intestinal contents and by the temperature of the extremities. An esophageal temperature device placed 24 cm below the level of the larynx in an intubated patient reflects an accurate cardiac temperature, but may not be widely available or practical. Oral thermometers are not accurate enough for therapeutic decision-making, and many do not measure temperatures below 34°C (94°F.) Tympanic thermometers very accurately reflect the temperature of the hypothalamus, but a thermometer that truly lies against the tympanic membrane is impractical unless the patient is anesthetized. External auditory canal thermometers that measure infrared emissions from the tympanic membrane (tympanic thermometers) are not as sensitive or reliable as true tympanic probes. Axillary temperatures are influenced too easily by external factors to be reliable in diagnosing or treating hypothermia.

Additional Signs of Hypothermia

Additional signs of hypothermia may be found in virtually every additional physiologic system, but are often nonspecific.

HEENT. Abnormal findings include decreased corneal reflexes, scleral edema, flushing, facial edema, epistaxis, rhinorrhea, and strabismus. Patients also may have mydriasis, and it should be noted that mild hypothermia usually does not depress pupillary light reflexes.

Respiratory. Patients initially have tachypnea, followed by progressive hypoventilation and apnea. Adventitious breath sounds may be heard. Bronchorrhea may be present.

Cardiovascular. Patients initially have tachycardia, followed by subsequent bradycardia. Patients with hypothermia develop both atrial and ventricular dysrhythmias and asystole. Peripheral vasoconstriction, hypotension, decreased heart tones, jugular venous distention, and hepatojugular reflux are seen.

Gastrointestinal. Because the body shifts blood flow toward the crucial systems involving the brain and the heart, gastrointestinal organs show signs of decreased blood flow and metabolism. The physical examination may reveal abdominal distention or rigidity and poor rectal tone. The patient also may experience ileus, constipation, and gastric dilatation.

Genitourinary. The patient may have polyuria as a result of cold diuresis, or may have anuria as a result of hypovolemia and renal failure.

Musculoskeletal. The patient will initially have increased muscle tone, followed by shivering. Shivering ceases below body temperatures of 32°C (90°F.) Patients also may have paravertebral spasm, opisthotonos, compartment syndrome, rigidity, and pseudo-rigor mortis.

Dermatologic. Patients may have a wide variety of dermatologic manifestations of hypothermia, including erythema, pallor, cyanosis, edema, pernio, frostnip, frostbite, panniculitis, cold urticaria, gangrene, and necrosis.

CNS. Neurologic changes in hypothermia vary widely. There are reported cases of patients who are normoreflexic and can still converse at 32°C (89.6°F.)[27] In general, the level of consciousness declines proportionately to the degree of hypothermia. Patients may have ataxia, dysarthria, amnesia, hyporeflexia, areflexia, hypoesthesia, poor suck reflex (in infants), and central pontine myelinolysis.

Psychiatric. Behavioral disturbances of hypothermia include apathy, irritability, impaired judgment, perseveration, mood changes, flat affect, paradoxical undressing, and altered mental status. Psychiatric conditions associated with or subsequently found in hypothermia patients include neuroses, psychoses, anorexia, depression, suicide, and organic brain syndrome.

Ancillary Testing

Hypothermia presents a multitude of laboratory abnormalities, and debates continue in the literature regarding appropriate "normal" and goals for rewarming and resuscitation. In view of the fact that many laboratory abnormalities also could be attributed to a secondary condition underlying hypothermia, it is prudent to obtain basic laboratory tests.

• **CBC:** Hematocrit increases as the plasma volume decreases. For each 1°C drop in core temperature, the hematocrit increases approximately 2%.

• **Serum electrolytes:** Hypokalemia or hyperkalemia may occur and should be monitored closely during the rewarming process. Serum potassium levels are temperature independent, and high serum potassium levels correlate with a poor prognosis. BUN and creatinine usually are elevated secondarily due to decreased renal blood flow.

• **Bedside glucose:** Hypothermia may cause either hyperglycemia or hypoglycemia, with the latter usually associated with a more prolonged state of hypothermia. The bedside glucose also is useful in screening for underlying conditions that may predispose the patient to hypothermia. Insulin is ineffective until the core temperature is above 30-32°C (86-89°F.). Hypoglycemia can cause mild hypothermia.

• **Coagulation studies:** Hypothermia directly affects coagulation through several mechanisms. The clotting cascade is impaired and plasma fibrinolytic activity is enhanced, producing a clinical picture that mimics disseminated intravascular coagulation (DIC). Clotting time and bleeding time are prolonged.[28] Platelet function is decreased, and there is decreased production of thromboxane B5. The PT and PTT may appear normal, since the blood is warmed in the laboratory.

• **Arterial blood gas:** The pH rises and the $PaCO_2$ falls as temperature drops. There is significant controversy in the literature regarding the mathematical correction of arterial blood gas results before interpretation. The newer literature suggests that arterial blood gas results should be interpreted without correction for temperature because arterial blood gases are warmed to body temperature before being processed.

Additional testing may include the following:

• **Creatine kinase (CK):** CK usually is elevated if the patient experienced the shivering response.

• **Amylase and lipase:** Hyperamylasemia is seen frequently and is postulated to correlate with the degree of temperature depression. As the abdominal examination may be unreliable, these enzymes may be helpful in identifying inflammation of the pancreas secondary to collapse of the microcirculatory system.

• **Pregnancy test:** Since most accidental hypothermia patients are male and since many secondary hypothermia victims are beyond childbearing age, there is insufficient literature to guide the use of this test.

• **Toxicology screen:** Hypothermia alters the metabolism of many drugs, both therapeutic and recreational. Physiologic response to a substance may be delayed by decreased absorption, decreased functionality of the liver and kidneys, and decreased responsiveness of the central nervous system. During rewarming, the patient may experience side effects beyond the normal half-life of the drug or medication.

• **Alcohol screen:** In addition to the delayed effects of metabolism of alcohol, hypothermic alcoholics may experience Wernicke's syndrome and require immediate treatment.

• **Fibrin and fibrin split products:** These studies may be useful if the patient presents with a clinical picture resembling DIC, as it may be attributed to occult sepsis.

• **Imaging studies:** There are no recommended imaging studies to aid in the diagnosis and treatment of hypothermia. The clinical presentation should guide the use of radiography, sonography, and computed tomography.

• **Electrocardiogram (ECG):** The PR, QRS, and QTc may be prolonged. The classic J wave, or Osborne wave may be seen. Atrial and ventricular dysrhythmias of many types occur as a result of hypothermia and rewarming, and the patient requires cardiac monitoring throughout the resuscitation.

Treatment

Search and Rescue/First Responder. This section addresses accidental hypothermia in an outdoor setting.

The first tenet of rescue for hypothermia victims is to perform a measured, safe extraction of the victim to prevent the creation of secondary victims among the rescuers. Unless the natural conditions (avalanche) require haste, it is safer to have a steady, progressive removal from the cold environment. Terrestrial hypothermia develops over hours to days, and immersion hypothermia develops over 30 minutes to a few hours. A few extra minutes to plan an orderly rescue will not worsen the hypothermia; hurried, rough handling could precipitate a lethal arrhythmia.

An awake person who is cold stressed but not yet hypothermic may be lightly shivering but behaving normally. If the person does not suffer from cognitive deficits, including apathy, and has full motor function, he or she can be warmed by mild exercise and ingestion of warm, sugared drinks. Caffeinated beverages and alcohol should be avoided. If the person has any cognitive or behavioral alteration, lack of fine motor coordination, or is shivering uncontrollably, he or she must be removed from the cold environment and placed in a prone position. Activate EMS, if possible, and prevent further heat loss through all available means of insulation.

Remove wet clothing once the patient is sheltered from the environment. A mildly hypothermic person may be able to assist with clothing removal, but if the patient has any motor incoordination, the clothing should be cut off. This assumes the availability of a commercial hypothermia insulation wrap system or an adequate and appropriate improvised system. An appropriate insulation wrap system is preferably integrated and contains as much dry insulation as possible (ground pads, sleeping bags) and a vapor barrier. If the elements of an insulation system are not available or if application is impractical, remove the patient to the best shelter available and remove as much water from the clothing as possible.

Stabilize all injuries, including cervical spine, if necessary. Dress open wounds prior to applying the insulating wrap.

If available, truncal rewarming can be accomplished by insulated hot water bottles or by direct body contact with a member of the victim's party. There is some controversy about active warming during this phase of treatment because active warming decreases shivering heat production; however, there are reports that active truncal warming via forced-air warming produces a warming pattern similar to that of shivering alone.[9] In addition, active warming preserves energy stores, reduces cardiovascular stress, and increases patient comfort.

Prehospital Care. *Moderate to Severe Hypothermia with Signs of Life.* Extraction of the patient with moderate to severe hypothermia must be accomplished as gently as possible to avoid precipitating ventricular fibrillation. Do not rub or manipulate the extremities. Place the victim supine to preserve cardiovascular stability, remove wet clothing, and bundle the patient in a hypothermia wrap for transport.

Assessment of the ABCs (airway, breathing, circulation) is essential, but do not delay removal of the patient from the cold environment to accomplish a detailed history and physical examination. Obtain core temperature if possible. Place the patient on a cardiac monitor. Start intravenous catheters if possible.

Patients with signs of life (respirations or a pulse) should be rewarmed as outlined above, or with one of several commercially available rewarming devices.

The core temperature continues to decline after the victim is removed from cold stress, a phenomenon known as afterdrop. Significant temperature drops (some clearly hypothermic) have been recorded in cold water swimmers, even if they are normothermic initially.[29] Afterdrop may persist for several hours in a moderate to severely hypothermic patient. Since the risk for the common terminal event in hypothermia (cardiac arrest) is a function of low heart temperature and the time spent at that temperature, it is beneficial to warm the patient, even if the warming is gradual.

Do not allow the patient to stand or sit during the rewarming. Do not place the patient in a warm bath or shower, as cardiovascular and/or metabolic instability may result, it is difficult to handle a wet, slippery patient in a bath, and transport should not be delayed. Do not give these individuals food or oral liquids.

Most hypothermic patients are volume depleted and require fluid administration. Normal saline or D5W may be used for volume resuscitation, and should be warmed to 40-42°C (104-108°F.)

Severe Hypothermia with No Signs of Life. There is a widely accepted adage that "no one is dead until he is warm and dead." This is particularly true of patients with severe hypothermia, who may be stiff from the cold with bradycardia and shallow respirations, making it difficult to assess respirations and pulse. Unless there are contraindications for CPR, it should be initiated.

Contraindications for CPR are:
- A non-compressible chest;
- Ice formation in the airway;
- Witnessed prolonged cardiac inactivity;
- Decapitation or other injury incompatible with life;
- Unsafe conditions for the rescuers;
- Signs of life.

This last item, signs of life, is particularly important in this situation. Adequate time (up to 3 minutes) must be allowed to determine if the patient has respirations or a heartbeat. In a severely hypothermic patient with a heartbeat, regardless of how slow, CPR could induce ventricular fibrillation.

Clearly, some individuals are dead or will not survive. In addition to the signs listed above, victims of non-immersion hypothermic cardiac arrest with a potassium > 9 mmol/L or a pH < 6.50 are not expected to survive.[30] Others have suggested potassium > 10 mmol/L alone predicts death.[7]

Apparent rigor mortis, fixed and dilated pupils, dependent lividity, and tissue deterioration are not reliable methods of determining the presence of life in hypothermic patients.

Indications for prehospital endotracheal intubation are identical to those in the normothermic environment. Avoid overinflation of the cuff tube with cold ambient air, as the air may expand with warming and kink the endotracheal tube. Ventilate the patient at half the normal rate to prevent reducing the already low CO_2 and causing ventricular fibrillation.

Place the patient on a cardiac monitor or automated external defibrillator. If the patient has ventricular fibrillation, attempt defibrillation with 2 watt sec/kg up to 200 watt sec. (The energy requirement for defibrillation does not increase with hypothermia.) If the attempt is unsuccessful, do not attempt again until warming starts. Successful defibrillation is difficult if the core temperature is less than 32°C. Do not attempt defibrillation if the patient has asystole.

Initial Emergency Department Management. On arrival in the emergency department, the initial management includes:
- *Airway*. As noted previously, the indications for intubation in the hypothermic patient are unchanged from normal circumstances and include any condition that would prevent the patient from safely maintaining an open airway.
- *Breathing*. The patient should be given warm, humidified oxygen if awake and breathing spontaneously. The intubated patient should be ventilated at half the normal rate, maintaining adequate oxygenation, as noted above.
- *Circulation*. Establish at least one large-bore IV line. Hypothermic patients will experience vasodilation during warming, which worsens any preexisting hypovolemia. An initial bolus of 250-500 cc of warmed crystalloid is indicated in patients with a core temperature less than 32°C.
- *Obtain a core temperature*. Esophageal measurement is preferable, but a continuous rectal thermometer may be more available.
- *Monitor vital signs, temperature and cardiac activity continuously.*
- *Start or continue CPR as indicated.*
- The cornerstone of therapy is rewarming.
- Defibrillate at 2 watt sec/kg up to 200 watt sec for ventricular fibrillation. If defibrillation fails due to low core temperature and ventricular fibrillation persists, repeat attempts after every 1°C rise in core temperature.
- Drugs normally used in cardiac arrest situations may not be effective at a core temperature less than 30°C (86°F). Bertyllium appeared to work in hypothermic conditions, but it was removed from the recommendations of the American Heart Association in 2000. There is anecdotal support for using amiodarone.[31] Procainamide may precipitate ventricular fibrillation and should be avoided.
- Vasopressors should be avoided as they have minimal effect on the vasoconstriction caused by hypothermia and may precipitate ventricular fibrillation. It is classically taught that all vasoconstrictors are ineffective; however, animal data suggest that vasopressors such as epinephrine increase coronary artery profusion pressure

and increase the chance of return of spontaneous circulation.[31]

• Steroids, barbiturates, and antibiotics have not been shown to increase survival rates from hypothermia.

• Remove all clothing and perform a secondary survey with particular attention to assessing conditions that predispose to hypothermia.

• Place an indwelling Foley catheter to measure urinary output. The Foley catheter containing a temperature probe has not been shown to be reliable during rewarming.

• A nasogastric tube may be placed to relieve gastric distention.

• Do not sedate the patient to suppress shivering when hypothermia is the primary problem.

• Obtain necessary laboratory and radiologic studies.

• Correct acid-base, fluid, and electrolyte abnormalities.

Rewarming Techniques. Hypothermia is an extremely heterogenous condition, and true evidence-based guidelines do not exist at this time. There have been no well controlled randomized trials comparing the various rewarming techniques. Treatment should be based on the presenting pathophysiology, the expertise of the provider, and the available resources. The key decision is whether to use active or passive rewarming techniques. The next decision concerns whether to use invasive or noninvasive measures, and whether to be aggressive with rewarming techniques.

Passive External Rewarming. In general, passive external rewarming is ideal for previously healthy adults with mild hypothermia. Cover the patient with dry insulating materials in a warm environment and allow the patient's thermoregulatory mechanisms to generate enough heat to warm the body. This method depends on the innate thermogenesis mechanisms, and thus will not be effective if the patient is colder than 30°C (86°F). This method is less ideal in older adults and in those with any inhibition of the shivering mechanism or inability to understand or obey commands.

Patients with cardiovascular instability, endocrinologic deficits, traumatic spinal cord transection, or peripheral vasodilation secondary to drugs or medication are not suitable candidates for passive rewarming. Infants require aggressive external warming to minimize metabolic energy expenditure and decrease mortality.

Passive external rewarming is reported to raise the core temperature 0.5-4°C/hour.[32]

Active External Rewarming. Active rewarming is the direct application of heat to the body and may be accomplished by delivering exogenous heat externally or to the core. External warming methods include heating pads, warm blankets, hot water bottles, radiant heat sources, warm-water immersion, and forced-air rewarming. Young, adult, acutely hypothermic patients are ideal candidates for active external rewarming.

When applying external heat to the body, the return of pooled, cool blood from the previously vasoconstricted extremities may further lower the core temperature, causing afterdrop and possibly causing dysrhythmias. Rewarming of the trunk alone may prevent this problem.

Forced Air Rewarming. Forced-air rewarming efficiently transfers heat to the skin surface using a commercial blanket device. The blanket forces hot air to circulate through the blanket covering the patient's skin, allowing for convective warming. This method is practical for emergency department use. Care should be taken to monitor for thermal injury to vasoconstricted extremities.

Radiant Heat Sources. Radiant heat sources are exemplified by the infant warmers used in hospital nurseries. Heated blankets and heating pads may be used on adult patients, but the patient must be awake and able to verbalize discomfort caused by contact with the skin to prevent thermal injury.

Warm Water Immersion. Warm water immersion is a theoretical method of active external warming, but it is difficult to monitor, resuscitate, and treat a patient in a warm bath. In addition, most emergency departments in the United States are not equipped with warm water tubs.

Active external rewarming is reported to increase the core temperature 1-4°C/hour.[32]

Active Core Rewarming. Active core rewarming is the direct application of the heat to the core of the body through heated inhalation, heated infusion, gastric lavage, peritoneal lavage, mediastinal lavage, hemodialysis, and/or extracorporeal warming. The use of active core rewarming must be guided by the circumstances and etiology of the hypothermia, the experience and expertise of the provider, and the availability of resources.

Heated inhalation is indicated in the emergency department when core temperature is lower than 32.2°C (90°F). Providing humidified heated air via mask is noninvasive, safe, and relatively easy to accomplish in the emergency department. Heat production is less than with other active core measures but can prevent further loss of heat through the respiratory process.

Heated infusions of crystalloid can raise body heat production in amounts relative to the amount of crystalloid infused. Commercial infusers heat crystalloids and blood to 40-42°C and provide a stable, consistent source of heated fluids. Crystalloids, but not blood, may be warmed in a microwave (2 minutes per 1 liter of fluid), mixed thoroughly, and administered to the patient. The plasticizer used in common polyvinyl chloride containers is stable enough to be used in a microwave.

Heated Lavage. Heated lavage is limited by the surface area involved and so should not be used as the sole rewarming technique. Gastrointestinal lavage involves direct application and removal of warm fluids to the upper and lower GI tracts through commercially available products. The method is limited by frequent occurrence of regurgitation in the patient. CPR must be stopped for this procedure.

Mediastinal lavage is an alternative used in patients who lack spontaneous perfusion. The heart is bathed in isotonic sodium chloride solution heated to 40°C through a left thoracotomy or a sternotomy incision. Thoracic lavage involves placement of two thoracostomy tubes, one in each hemithorax. Warm saline is infused in the higher, anterior thoracostomy tube and drained via the lower, posterior thoracostomy tube. Care should be taken to avoid infusing fluids under pressure without adequate drainage as a tension pneumothorax may ensue. Peritoneal lavage is accomplished via an infraumbilical incision. A 1.5% dextrose dialysate is heated to 40-45°C and infused. One advantage of this technique is that direct hepatic rewarming helps to activate the enzymes active in the detoxification of drugs in an overdose. However, peritoneal lavage may worsen hypokalemia in hypothermia patients.This has been reported to raise the core temperature 1-3°C/hour.[32]

Extracorporeal blood rewarming is a heroic measure indicated only in severe hypothermia. Most methods require special equipment and expertise to accomplish, and are not always available in the emergency department. Hemodialysis has the advantage that it is widely available and may be advantageous to patients with electrolyte abnormalities, renal failure, or intoxication with a substance that can be removed by dialysis. This has been reported to raise the core temperature 2-3°C/hour.[32] Venovenous rewarming requires a central venous catheter for removal and a larger peripheral catheter for return of heated blood. Arteriovenous rewarming accomplishes a similar function using a femoral artery catheter and contralateral femoral venous catheters. Cardiopulmonary bypass (CBP) should be considered in unstable hypothermic patients in cardiac arrest. It has been reported to raise the core temperature 7-10°C/hour.[32] CBP requires anticoagulation and may worsen the coagulopathies of hypothermia.

Recently, an endovascular warmer, generally used to cool patients after a cardiac arrest, was used to successfully rewarm a hypothermic patient, with a rise in temperature of 3°C/hour.[33]

Diathermy is heat delivered ultrasonically to the deep tissues by the conversion of energy. It is contraindicated in patients with frostbite, severe edema, and implanted hardware.

Disposition

Healthy adults with minor hypothermia who recover completely may be discharged. It is necessary to ensure that they safely return to the appropriate environment without risk of another episode of hypothermia. Clearly, frostbite is a major complication of hypothermia.

Almost all other cases of hypothermia require admission to the intensive care unit. Stabilization of the core temperature is the initial goal of therapy, followed by diagnosis and treatment of any underlying disorder(s) that predispose to hypothermia. Infection is common. Hypothermia affects endothelial cell adhesion and allows bacteria to cross membrane barriers.[5]

Conclusion

Patient education and prevention are needed in the area of hypothermia. Adequate clothing, conditioning, and judicious use of the outdoor environment in extreme weather are essential elements in the prevention of this condition.

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Physician CME Questions

41. There are several ways to rewarm a cold patient. The most rapid way is:
    A. cardiopulmonary bypass.
    B. warmed IV fluids.
    C. heated inspired oxygen.
    D. warmed blankets.

42. All of the following are causes of secondary hypothermia except:
    A. advanced age.
    B. alcohol intoxication.
    C. emphysema.
    D. malnutrition.

43. Loss of heat when submerged in icy water is an example of:
    A. radiation.
    B. convection.
    C. conduction.
    D. evaporation.

44. A cold water swimmer leaves the lake normothermic and enters a heated cabin. Several minutes later, he is hypothermic. This is an example of:
    A. exhaustion.
    B. rhabdomyolysis.
    C. vasoconstriction.
    D. afterdrop.

45. The presence of a J wave:
    A. is pathonomonic of hypothermia.
    B. can be seen in lead II.
    C. is associated with a bad prognosis.
    D. is most prominent at 30°C.

46. A patient is found in the snow. It is unclear how long he has been there. He has a core body temperature of 20°C and no signs of life. There is no pulse or respiration. Which of the following would suggest that resuscitation efforts are futile?
    A. dilated pupils
    B. frostbite of his nose and ears
    C. potassium 12.5 mmol/L
    D. pH 7.00

47. Which of the following is true about ventilation in a severely hypothermic patient?
    A. There is no need to ventilate until the pulse is restored.
    B. Ventilation should be at half the rate as for a normothermic patient.
    C. Ventilation should be at half the volume as for a normothermic patient.
    D. Ventilation should be exactly the same as for a normothermic patient.

48. Which of the following is true about initial defibrillation in a severely hypothermic patient?
    A. There is no need to defibrillate even if he is ventricular fibrillation.
    B. Defibrillation should be at half the Joules as for a normothermic patient.
    C. Defibrillation should be a twice the Joules as for a normothermic patient.
    D. Defibrillation should be exactly the same as for a normothermic patient.

49. Which of the following statements about arterial blood gases is true?
    A. As temperature drops, pH drops.
    B. As temperature drops, $PaCO_2$ rises.
    C. There is no change in either pH or $PaCO_2$ with temperature change.
    D. While pH and $PaCO_2$ change, arterial blood gases should be interpreted without correction for temperature.

50. Patients who present with severe hypothermia:
    A. should be admitted to the ICU.
    B. can be discharged home from the ED once they are normothermic and awake.
    C. should be admitted to an observation unit for 6-12 hours.
    D. only need to be admitted if they have renal failure.

CME Answer Key

41. A; 42. C; 43. C; 44. D; 45. B; 46. C; 47. B; 48. D; 49. D; 50. A

In Future Issues

Appendicitis

Emergency Medicine Reports

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- understand the differential diagnosis of the entity discussed;
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Accidental Hypothermia

Commonly Worn Clothing in Increasing Effectiveness to Prevent Hypothermia

- Shirt, pants, socks, and shoes
- Shirt, pants, socks, shoes, jacket
- Windproof, waterproof jogging suit, socks, shoes
- Fleece shirt and pants, socks, shoes
- Jacket, thermal long underwear, socks, shoes
- Ski jacket and pants, thermal long underwear, sweater, goggles, socks, boots
- Down-filled cold weather parka with hood, ski pants, thermal long underwear, thick socks, and boots
- Expedition suit

Physiologic Changes Seen with Hypothermia

	Body Temperature	Physical Changes
Mild	35°C	Maximal shivering
	34°C	Amnesia, behavioral changes
	33°C	Ataxia
Moderate	32°C	Obtunded
	31°C	Shivering stops, dilated pupils
	30°C	Cardiac arrhythmias
	29°C	Coma
Severe	28°C	Ventricular fibrillation risk
	27°C	Loss of voluntary movement, reflexes
	26°C	No response to pain
	24°C	Hypotension, bradycardia
	23°C	Loss of corneal reflex
	19°C	EEG flat
	18°C	Asystole
	13.7°C	Lowest survived temperature

Some Conditions that Predispose to Hypothermia

Endocrine
Hypopituitary, hypoadrenal, hypothyroid, diabetes
Nutrition
Hypoglycemia, starvation, excessive exertion, anorexia nervosa
Medications
Vasodilators, overdose of sedatives or psychotropic medications
Skin
Burns, psoriasis, icthyosis, exfoliative dermatitis
Neurological
Neuropathies, acute spinal cord injuries, trauma, stroke, subarachnoid hemorrhage, hypothalamic dysfunction, Parkinson's, tumor, multiple sclerosis
Other
Sepsis, pancreatitis, cancer, uremia, vascular insufficiency, extremes of age

Secondary Causes of Hypothermia

Medications
- Phenothiazines
- Barbiturates
- Neuromuscular blocking agents

Exposures
- Organophosphates
- Heroin
- Carbon monoxide
- Alcohol

Endocrine
- Hypopituitary
- Hypoadrenal
- Hypothyroid

Other
- Sepsis
- Cancer
- Pancreatitis
- Uremia
- Starvation
- Anorexia nervosa

Supplement to *Emergency Medicine Reports*, February 16, 2009: "Accidental Hypothermia." *Author:* **Angela Gardner, MD, FACEP**, Assistant Professor, Department of Surgery/Emergency Medicine, University of Texas Medical Branch, Galveston.