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Hypothermia

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Abstract

A decrease in body temperature below 35°C (<95°F) is defined as hypothermia. Accidental hypothermia occurs when a person's body temperature drops involuntarily as a result of exposure to cold. Thousands of people lost their lives due to both trauma and hypothermia in natural disasters such as earthquakes, tsunamis, avalanches, and floods. In hypothermia, depending on the degree of body temperature, the functions of the body systems are suppressed. The staging of hypothermia classifications was made based on the measurement of core temperature, clinical symptoms, and risk of cardiac arrhythmia. The main precautions for hypothermic patients in the prehospital setting are removal from the cold environment, insulation, rewarming, and rapid transfer to the hospital. The most effective internal rewarming strategy is extracorporeal life support in the hospital setting.

Keywords: Hypothermia, disaster, rewarming

Introduction

A decrease in body temperature below 35°C (<95°F) is defined as hypothermia. Primary (accidental) hypothermia occurs when a body temperature drops involuntarily as a result of exposure to cold. Secondary hypothermia develops as a result of disruption of temperature regulation due to various underlying pathologies such as infection, hypoglycemia, and malnutrition. Mortality in patients with secondary hypothermia is usually determined by the underlying condition rather than the hypothermia.[1,2] This review will provide information about primary (accidental) hypothermia resulting from disasters.

Epidemiology

Accidental hypothermia has been known since ancient times. Accidental hypothermia also affects people exposed to cold environments, such as those who live outdoors, work, and the homeless, but its most devastating effects are seen in natural disasters.[3]

"Only human beings can recognize catastrophes, provided they survive them; nature recognizes no catastrophes" (Max Frisch, Man in Holace, 1979). Disasters are a reality that affects our lives, which human beings have encountered since their existence and will encounter in the future. Thousands of people lost their lives due to both trauma and hypothermia in natural disasters such as earthquakes, tsunamis, avalanches, and floods. A disaster is an event where the number of victims exceeds or significantly depletes the technical and medical resources of the local rescue system. In addition, damage to treatment centers such as hospitals in the region, damage to transportation mechanisms, and other problems such as power cuts increase the severity of the damage.[4]

Earthquakes start suddenly and cause more injuries and deaths at night than daytime disasters. From 1994 to 2013, earthquakes killed an estimated 1.35 million people and has been responsible for the displacement of 218 million people. More than 80% of those killed by earthquakes have been in China, Japan, Pakistan, Turkey, former USSR countries, Peru, Chile, and Italy. The earthquake that occurred on February 6, 2023, in Turkey affected 13 million people, with 45 000 deaths and over 100 000 injured.[5-7]

Although avalanches did not affect large numbers of people as much as earthquakes, they caused numerous deaths each time. The avalanche disaster that caused the most deaths in the world was in Peru in 1962, with 4000 deaths. Accidental hypothermia was reported as the sole cause of death in only about 1% of avalanche victims. It usually takes at least 1 hour for a victim's body temperature to drop to <30°C after an avalanche; however, the cooling rate of buried victims can reach 9°C/h.[6,8]

Floods are the most common disasters worldwide. Climate change increases precipitation and increases the risk of flooding. The North Sea flood (Netherlands) killed 2551 people in 1953, and Hurricane Katrina (United States) killed 1464 people in 2005.[6]

Since trauma and drowning are important causes of death in natural disasters, it is difficult to give the incidence of death due to isolated accidental hypothermia. In the USA, 15 000 hospital admissions and 1500 deaths due to accidental hypothermia are reported annually. The annual incidence of accidental hypothermia in Europe and New Zealand ranges from 0.13-6.9/100 000 people. The annual incidence of death from accidental hypothermia has been reported to be 1.81-2.2/100 000 people in the UK and 5/100 000 people in Poland.[9-11] Hypothermia was responsible for 0.2% of deaths in the tsunami that followed the Great East Japan earthquake.[12]

Pathophysiology

Body temperature is tightly regulated at around 37 ± 0.5°C with daily variations under normal conditions. Central (hypothalamic) and peripheral thermoregulation (peripheral vasoconstriction and vasodilation, shivering, and sweating) are autonomic regulation mechanisms of body temperature.[6] When the autonomic and compensatory physiological responses regulating normothermia are insufficient when exposed to cold environments, the functions of body systems are affected by the degree of body temperature, causing depressive functionality in organs at different degrees. The rate of decrease in body temperature is affected by various factors such as age, body size, ability to move, the thickness of clothing, thickness of

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subcutaneous fat, adaptation to cold, concomitant injury or existing diseases, type of cold environment (air, snow, or water), and environmental conditions that increase cooling (wind, rain, and snowfall).[2]

Cardiovascular System

When the body temperature falls below 36°C, sympathetic nervous system activation and catecholamine release occur, resulting in tachycardia, increased vascular resistance, increased cardiac afterload, increased mean arterial pressure, and increased cardiac output. This physiological response increases oxygen and energy consumption. If the body temperature continues to drop (<32°C), cardiovascular function gradually deteriorates. Atrial and ventricular arrhythmias may occur due to the prolongation of the action potential duration and the decrease in the transmembrane resting potential, and bradycardia may occur due to the decrease in the automation of the heart cells. Ventricular fibrillation (VF) or asystole may occur when the body temperature drops below 28°C. Widening of the QRS complex, J (Osborn) wave, prolonged QT interval, and T wave inversion can be seen on the electrocardiogram. There is a decrease in cardiac output secondary to both increased afterload (due to an increase in systemic arterial resistance) and bradycardia and decreased calcium sensitization. There is also a decrease in cardiac contractility.[2,13,14]

Central Nervous System

Cerebral oxygen consumption simultaneously decreases by 6% with every 1°C decrease in body temperature. Impairment in mental functions begins after a decrease of 4°C in body temperature. Hypothermia-induced deterioration in cerebral homeostasis is defined as the transient organic brain syndrome and includes behavioral changes, disorientation, amnesia, apathy, and dysarthria. Loss of consciousness has been reported in people with a body temperature <30°C. The human electroencephalogram is abnormal when the body temperature is <33.5°C, suppressed at 22°C, and quiescent at <19-20°C. Pupils dilate, and the light reflex disappears at 28°C. When the body temperature drops to 28-30°C, the peripheral nervous system is suppressed, and reflexes become unresponsive and completely absent.[2,15]

Respiratory System

In hypothermia, although there is initial hyperventilation, a decrease in body temperature results in a decrease in tidal volume, respiratory rate, and lung compliance and an increase in dead space. When the body temperature drops, both oxygen consumption and carbon dioxide (CO_2) production decrease. Apnea can be observed at <28°C. Although there is the potential for non-cardiogenic pulmonary edema due to fluid shifts, pulmonary edema is not a typical complication of hypothermia and is common after rewarming procedures to deep hypothermia.[16]

Fluid–Electrolyte Balance

Relative central hypervolemia due to an increase in hematocrit, peripheral vasoconstriction, and elevation in arterial blood pressure in hypothermia suppresses antidiuretic hormone secretion and results in “cold diuresis.” Loss of fluid and electrolyte reabsorption in the distal tubules also contributes to cold diuresis.[17] Decreased consumption of oxygen results in impaired renal metabolism and tubular function, but serum sodium, calcium, chloride, and potassium levels remain within the normal range until the body temperature drops to 25°C.[2]

Blood and Coagulation Parameters

Blood viscosity increases by 2% for every 1°C decrease in body temperature, resulting in hematological concentration and increased hematocrit. In hypothermia, tissue hypoxia occurs as the oxyhemoglobin curve shifts to the left. Hypothermia causes a decrease in enzyme functionality, leading to the prolongation of prothrombin time and coagulopathy. Hypothermia causes thrombocytopenia by causing the sequestration of platelets in both the portal circulation and the liver. Clinically significant coagulopathy develops at a body temperature <34°C.[18-20]

Rescue Collapse and Afterdrop Phenomenon

Cardiovascular collapse that develops during the removal or transfer of hypothermic patients is called rescue collapse. The underlying mechanism is not well understood and may be multifactorial. In hypothermic patients, rescue collapse may be incidental but is more commonly caused by hypovolemia, cardiac arrhythmias triggered by interventions such as central venous catheterization, biochemical changes, or most commonly mechanical stimuli such as sudden movement. The afterdrop phenomenon is a decrease in body temperature even after rewarming. The main cause of afterdrop is heat transfer between cold and warmer body parts as a result of reperfusion of cold body parts during rewarming.[21,22]

Diagnosis and Staging

The diagnosis of accidental hypothermia can be difficult outside of the hospital. Accidental hypothermia should be considered and ruled out if the trunk feels cold by touching in patients with a history of cold exposure or predisposing conditions.[23]

If there is no opportunity or condition for body temperature measurement, a clinical diagnosis can be made by evaluating vital signs. Vital signs decrease linearly as the body temperature decreases. In this situation, using the level of consciousness is the best way to assess hypothermia. However, the level of consciousness can also be affected by factors other than body temperature, such as poisoning and trauma.[24]

The definite diagnosis and the determination of the level of accidental hypothermia can be made by measuring body temperature. Since the external parts of the body cool faster than the core, body temperature should be measured as close as possible to vital organs such as the brain and heart.[23] The gold standard for out-of-hospital measurement of core temperature is the esophageal measurement. An internal temperature taken from the lower one-third of the esophagus is strongly correlated with the temperature of the heart and can measure rapidly changing temperatures in real time. This invasive method is difficult to implement outside the hospital.[25] Epitympanic measurement with the thermistor probe placed close to the eardrum reliably reflects brain temperature and is a non-invasive, safe, and practical method alternative to esophageal measurement. Before the probe is positioned, it must be ensured that the external auditory canal is open. Rectal and bladder temperatures are measured mainly in the hospital. Insertion of the rectal tube (up to 15 cm deep) is impractical in the prehospital setting.[26]

Staging of hypothermia in prehospital areas is based on clinical status, the presence of vital signs, and body temperature measurement, if present. Various classifications have been proposed for the out-of-hospital and in-hospital management of hypothermic patients. Danzl et al[27] made a classification based on the measurement of core temperature, Durrer et al[28] based on clinical symptoms, and Matz[29] based on a body temperature of 32°C, which creates a risk of cardiac arrhythmia (Table 1). Clinical signs alone should not be relied upon to estimate the severity of hypothermia,

Table 1. Staging and Symptoms of Hypothermia According to Core Temperature[27-29]

CT, °C		Symptoms	Staging
Danzl et al			
>32°C-<35°C	35°C	• Maximal shivering; increase in metabolic rate and blood pressure	Mild
	34°C	• Tachycardia, then progressive bradycardia; normal blood pressure; maximum respiratory stimulation; amnesia, dysarthria, poor judgment, maladaptive behavior	
	33°C	• Ataxia and apathy; linear depression of cerebral metabolism; tachypnea, then progressive decrease in respiratory minute volume; cold diuresis	
>28°C-≤32°C	32°C	• Stupor: 25% decrease in oxygen consumption	Moderate
	31°C	• Extinguished shivering thermogenesis	
	30°C 29°C	• Atrial fibrillation and other dysrhythmias; poikilothermia; cardiac output two-thirds normal; both hyperglycemia and hypoglycemia may occur	
		• Progressive decrease in the level of consciousness, pulse, and respiration; pupils dilated; paradoxical undressing	
>20°C-≤28°C	28°C 27°C	• Decreased ventricular fibrillation threshold; 50% decrease in oxygen consumption and pulse; hypoventilation	Severe
	26°C	• Loss of reflexes and voluntary motion	
	25°C	• Major acid–base disturbances; no reflexes or response to pain	
	24°C	• Cerebral blood flow: one-third of normal; loss of cerebrovascular autoregulation; cardiac output 45% of normal; pulmonary edema may develop	
	23°C	• Significant hypotension and bradycardia	
	22°C	• No corneal or oculocephalic reflexes; areflexia	
	21°C	• Maximum risk of ventricular fibrillation	
		• 75% decrease in oxygen consumption	
≤20°C	20°C	• Lowest resumption of cardiac electromechanical activity, pulse 20% of normal	Profound
	19°C	• Electroencephalographic silencing	
	18°C	• Asystole	
	13°C	• 13.7°C is the lowest adult accidental hypothermia survival degree.	
	10°C	• 92% decrease in oxygen consumption	
	9°C	• The lowest therapeutic hypothermia survival degree	
Durrer et al			
> 32°C-< 35°C		Alert shivering	I
>28°C-≤32°C		Drowsy nonshivering	II
≥24°C-≤28°C		Unconscious	III
<24°C		Not breathing	IV
Matz			
>32°C-<35°C			Safe zone
≤ 32°C			Danger zone

CT, core temperature.

but a comprehensive assessment of conditions including the patient, area, mechanism of injury, pre-existing diseases, ambient temperature, and exposure time to cold should be considered.[2,10]

Treatment

Out of Hospital

Land and air vehicles, suitable thermometers, chemical heat packs and heating devices, and body insulation materials should be available in areas where there is a risk of hypothermia. Achieving normothermia in out-of-hospital treatment is important, but effective prehospital rewarming is unlikely in most emergency medical systems due to limited equipment and the rapid transfer of victims. Therefore, it is more important to prevent heat loss. The main precautions for hypothermic patients in the prehospital setting are removal from the cold environment, limiting further heat loss, and rapid transfer to the hospital.[30]

Mild Hypothermia (Stage 1)

Patients with mild hypothermia are usually fully awake. They can usually be managed in a prehospital setting. Passive rewarming by removing the patient from the cold environment, optimizing isolation, offering food and hot beverages if there is no severe or surgical trauma, and encouraging active movement are usually sufficient.[30]

Moderate or Severe Hypothermia (Stage 2 or 3)

In the management of patients with moderate or severe hypothermia, patient immobilization, whole-body isolation and adequate oxygenation, active/passive rewarming, and rapid transfer are the basic principles. Detection of vital signs such as pulse or breathing should be extended by 1 minute. It should be monitored before transport to detect arrhythmias that occur during the patient's movement.[31]

Immobilization

Patients with moderate or severe hypothermia should be immobilized on a stretcher in a horizontal position to prevent rescue collapse. Ventricular fibrillation development threshold is low in these patients, so care should be taken during rescue and transportation. During rescue and transport, hard movements should be avoided as much as possible, and if it is not possible to avoid, movements of the limbs and trunk should be done slowly and with great care.[1,2]

Body Insulation

The purpose of full-body insulation is to prevent further heat loss, rather than rewarming. Protection against cold, wind, and humidity should be provided primarily. Wet clothing should be cut in a protected environment. A vapor barrier should be added in wet or windy conditions or if wet clothing cannot be removed. If there are no materials produced for this purpose in the area, they can be wrapped with improvised materials such as aluminum foil, jackets, raincoats, tents, and bubble wrap.[31,32]

Rewarming

The term passive rewarming is defined as if the patient increases body temperature without exogenous heat, and active rewarm is defined as if the patient increases it with exogenous heat. Active rewarming can be external or internal, depending on the method of heat transfer. Active external rewarming can be achieved using chemical/electric heat packs and hot air. Heat transfer occurs most efficiently when heat packs are applied to the armpits, chest, and back, but these packs should not be applied directly to the skin because of the burn risk. Active internal warming can be initiated through warm intravenous (IV) infusions, peritoneal, bladder, or thoracic lavage with warm fluids, and extracorporeal life support (ECLS). Warm IV infusion is the fastest method of out of hospital.[31,32] The IV route is the first-choice method, but it may be difficult to apply due to peripheral vasoconstriction caused by hypothermia. The intraosseous (IO) route can be used as an alternative.[30] Intravenous or IO fluids (preferably isotonic crystalloid solutions) should be warmed to 42°C or at least body temperature and given in boluses according to vital signs. Heated fluids can limit secondary cooling and protect lines from freezing, but they have little effect on actual rewarming. Therefore, complete rewarming of patients with moderate-to-severe hypothermia should not be done in the field and should be transferred quickly to the hospital.[2,33]

Oxygenation

Adequate oxygenation is essential to stabilize the myocardium in hypothermic patients. Pulse oximetry may not be reliable in hypothermic patients due to peripheral vasoconstriction. Non-intubated patients should receive supplemental oxygen through a mask or nasal cannula. Inhaling heated, humidified oxygen may help prevent further heat loss, but it has little effectiveness. If the patient does not respond to oxygenation, airway safety should be ensured with endotracheal intubation or a laryngeal mask to protect the airway and ensure adequate oxygenation.[32] Indications for anesthesia induction and endotracheal intubation are the same as in normothermic patients. In mild hypothermia, opioids and neuromuscular blockers are given at lower doses and longer intervals than in normothermia. It should be kept in mind that opioid metabolism is decreased and neuromuscular blockade is prolonged in these patients. In patients with a body temperature below 30°C, no benefit has been demonstrated for the administration of antiarrhythmic agents such as amiodarone or vasopressors such as epinephrine and vasopressin.[34]

Cardiac Arrest

In a hypothermic patient with cardiac arrest (CA), cardiopulmonary resuscitation (CPR) should not be initiated or terminated if there are clear signs of irreversible death, including livor mortis, avalanche burial with a completely occluded airway for more than 60 minutes, and the rescuers are distressed or exhausted, but rigidity (rigor mortis) in the hypothermic patient cannot be a reliable indicator of death.[35] It may be difficult to diagnose CA in an unconscious patient in a cold environment. Vital signs may be minimal or difficult to detect. Rescuers should try to find vital signs for 60 seconds. The use of electrocardiography, end-tidal carbon dioxide ($EtCO_2$) measurement, or point-of-care ultrasonography can help detect cardiac activity and cardiac output, but these equipment are impossible to find in the field.[8,11] Patients with hypoventilation, apnea, malignant arrhythmias, systolic blood pressure <80 mmHg, pulseless electrical activity, pulseless ventricular tachycardia, VF or asystole, dilated pupils, and hypocapnia ($EtCO_2$ < 10 mmHg) should be transferred to a center with direct cardiopulmonary bypass (CPB) facilities for extracorporeal rewarming. Continuous CPR should be performed during transport.[36] Chest compressions and ventilation should be performed in a hypothermic patient with CA as in a normothermic patient. Early CPR improves the survival of a hypothermic patient in CA, even if prolonged. In case of persistent VF after 3 defibrillations, further attempts are made until the core temperature is >30°C. Adrenaline is not administered in patients whose core temperature is < 30°C. In patients with a core temperature of >30°C, the frequency of adrenaline administration is increased to 6-10 minutes. When normothermia (≥35°C) is achieved, standard protocols should be resumed.[31,36]

In Hospital

In-hospital treatment options depend on circulatory status, stage of hypothermia, and available resources. Patients with stable circulation can be warmed with passive/active external rewarming techniques.[11]

In patients with spontaneous circulation and a body temperature of 33-36°C, the target of rewarming should be normothermia with a core temperature of approximately 37°C. Patients who develop hypothermic CA or who have hemodynamic instability require circulatory support in addition to active internal rewarming. This is best achieved by rewarming with ECLS.[37] The ideal rewarming rate is unknown, but a rewarming rate of ≤5°C/h is recommended. A slower rewarming rate (2°C/h) was associated with improved survival and better neurologic recovery. Non-ECLS rewarming methods should be considered in these patients only when ECLS is not present and cannot be achieved within 6 hours.[38] Techniques and effectiveness of rewarming are shown in Table 2.

The use of ECLS may be considered in the following situations:[39]

- Failure to improve with externally active and minimally invasive rewarming methods
- Life-threatening arrhythmia,
- Hypotension (systolic blood pressure < 90 mmHg),
- Respiratory failure, and
- Refractory acidosis.

Table 2. Effectiveness of Rewarming Techniques[2,10]

Rewarming Techniques	Rewarming Rate (°C/h)	Indication
Without Cardiac Support		
Warm environment and clothing, warm sweet drinks, and active movement	~2 (dependent on metabolic rate)	Mild HT
Active external and minimally invasive rewarming (warm environment, chemical, electric, or forced air heating packs or blankets, and warm parenteral fluids)	0.1-3.4	Moderate or severe HT with cardiac stability
Bladder lavage	<0.5	Not recommended; rewarming is intermittent and slow because of the small surface area
Gastric lavage	~0.5-1	Not recommended. The risk-to-benefit ratio is unacceptably high
Peritoneal dialysis	1-3	Uncertain
Hemodialysis	~2-4	Uncertain
Thoracic lavage	~3	Profound HT when ECMO/CPB is not available
Venovenous ECMO	~4	Uncertain
With Cardiac Support		
Venoarterial ECMO	~6	Severe HT with cardiac instability or profound HT
Cardiopulmonary bypass	~9	When ECMO is not available: Severe HT with cardiac instability or profound HT

ECMO, extracorporeal membrane oxygenation; HT, hypothermia.

Intravascular volume decreases due to extravascular fluid shift, insufficient fluid intake, and cold diuresis in moderate-to-severe hypothermia. Volume replacement in these patients should be performed carefully and with central venous pressure monitoring, if possible.[11]

Extracorporeal cardiopulmonary resuscitation (ECPR) followed by ECLS rewarming may be associated with higher survival and more favorable outcomes than conventional CPR alone in patients with accidental hypothermia without vital signs. Venoarterial (VA) ECMO is the preferred method of ECPR because anticoagulation requirements are minimal and because VA ECMO may be able to provide circulatory and respiratory support beyond the return of spontaneous circulation.[40]

Conclusion

Disasters that cause destruction and death have been affecting our lives since our existence and will continue to affect us. Accidental hypothermia involved in these disasters is among the causes of death/injury in addition to trauma and suffocation. Although the priority is to take measures to prevent death and injury in disasters, injuries and deaths resulting from accidental hypothermia can be reduced by early intervention, effective insulation, and rapid early rewarming after disasters.

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