Accidental Hypothermia: 'You're Not Dead Until You're Warm and Dead'

JOHN L. FOGGLE, MD, MBA, FACEP

INTRODUCTION

The classic teaching in medical school regarding hypothermia is "you're not dead until you're warm and dead." More precise definitions than the medical school axiom exist. Hypothermia is a drop in core body temperature <35°C, (or per history or trunk palpation when an initial core temperature measurement is unavailable) due to cold exposure which, if not reversed, can lead to mental and physical impairment, hypoxemia, hypotension, acidosis, unconsciousness, arrhythmia, and death. Modern approaches to rewarming have improved survival from accidental hypothermia. This article reviews the epidemiology and classification of accidental hypothermia and reviews traditional and recently developed warming techniques that reduce morbidity and mortality in the setting of severe accidental hypothermia.

EPIDEMIOLOGY

The exact incidence of hypothermia deaths in the United States is unknown, and existing data is likely underestimated. The Centers for Disease Control and Prevention (CDC) reports nearly 17,000 hypothermia-related deaths in the United States between 1999 to 2011. Of the almost 1500 annual deaths, approximately 2/3 are male and nearly half of those who succumb are elderly. Fifty percent of deaths are from accidental causes. [1]

Common risk factors for accidental hypothermia include homelessness, poverty, mental illness, extremes of age, diabetes, cardiovascular disease, and alcohol and illicit drug use. Recreational activities related to climbing and skiing, resulting in cold exposure, and water sports, resulting in cold immersion, make up another large cohort of hypothermia cases.

CLASSIFICATION

There are a number of different classification systems used to organize the physiologic response to hypothermia. All are based on core temperatures, which can be determined by low-reading rectal or esophageal thermometers, or through epitympanic measurements. Epitympanic measurements may be considerably lower than the actual core temperature if the environment is very cold, or if there is water or snow in the external auditory canal. [2,3] Rectal temperatures can lag behind the true core temperature, especially in severe hypothermia. [4,5,6] The most accurate measurement, especially during rewarming, is an esophageal probe in the lower one-third of the esophagus, but this is only an option in an intubated patient.

The most common hypothermia classification system used in the United States is a three-stage system relying on the single lowest core temperature measurement:

MILD	32–35°C	(90–95°F)
MODERATE	28–32°C	(82–90°F)
SEVERE	<28°C	(<82°F)

The Four-stage Swiss System (**see Table 1**) is used to estimate core temperature at the scene, with stages based on clinical signs that roughly correlate with the core temperature. [7] The Swiss classification splits the severe group into "unconscious" (24–28°C) and "no vital signs" (<24°C) and can be used to guide treatment once a core temperature is measured. One of the limitations of both the Swiss model, as well as other systems, is that there is much overlap and clinical findings may not correspond to classification. [8]

Each of the classification systems correspond to the physiologic response to hypothermia. In mild hypothermia, the initial response to a decrease in core temperature is peripheral vasoconstriction and increased metabolic heat production from shivering. [9] Cardiac output and respiratory effort

Table 1. Swiss Hypothermia Staging System

Stage	Core Temperature	Clinical Findings	Treatment Approach
HT-I	32–35°C	Conscious, shivering	Warm environment and clothing, warm liquids
HT-II	28–32°C	Impaired consciousness, not shivering	Active external, warmed fluids, minimally invasive internal rewarming
HT-III	24–28°C	Unconscious, vitals signs present	All of the above plus airway control; consider ECMO or CPB if patient deteriorates
HT-IV	< 24°C	No vital signs	Restore vital signs via CPR or defibrillation if possible, followed by ECMO or CPB

ECMO denotes Extracorporeal membrane oxygenation, CPB is Cardiopulmonary bypass, and CPR is Cardiopulmonary resuscitation increase, as does oxygen consumption. When the core temperature drops below 32° C, metabolic activity decreases and bradycardia and diminished myocardial contractility is noted. Additionally, hypoventilation with concomitant carbon dioxide retention, hypoxia, and respiratory acidosis can occur.

As core temperature drops below 30° C, multiple organ systems are affected. Cardiac irritability results in dysrhythmias, and diminished brain metabolism results in increased irritability, confusion, apathy, and lethargy, and can proceed to somnolence and coma. [10] Other systems are impacted as well. Coagulopathy, renal dysfunction and cold diuresis occur, and endocrine and immunologic changes are seen in hypothermic patients. [9,11]

MANAGEMENT OF ACCIDENTAL HYPOTHERMIA

The rationale for aggressive treatment in accidental hypothermia is that the brain can tolerate cardiac arrest for up to 10 times longer at 18°C than at 37°C. [12] A full neurological recovery may be possible even after prolonged cardiac arrest as long as asphyxia does not precede the development of severe hypothermia. **It is essential to recognize that unless there are obvious lethal injuries, a fatal illness, prolonged asphyxia, or if the chest is incompressible, survivability is possible in a hypothermic victim even when there are fixed pupils or early signs of rigor mortis.**

PASSIVE REWARMING

The principles of treating mild hypothermia in victims who still have a carotid pulse and active respirations, (Swiss Hypothermia Stage I), with core body temperatures of 32 -35°C, remain straightforward and uncontroversial. Such a patient is conscious and is likely shivering, although they may be lethargic and bradycardic. Passive external rewarming should begin in the field, even before emergency department arrival. It constitutes removing wet garments along with insulating the victim by using dry clothing, sleeping bags, or blankets. It is important to note that victims will continue cooling, which is known as "afterdrop," after removal from a cold environment. This can result in a worsening Swiss Hypothermia Stage with life-threatening cardiac arrhythmias.

ACTIVE EXTERNAL REWARMING

Warm blankets and warm bags of saline especially to the core (axilla, back, chest, and groin), as well as warm (40°C), humidified oxygen delivery by mask, are the initial recommended emergency department treatments for Swiss Hypothermia Stages I and II. Impaired consciousness and the absence of shivering are expected in Stage II. Passive adjuncts like raising the ambient room temperature to >32°C and contact rewarming with a Bair Hugger® also facilitate external rewarming, while warm water immersion (40°C) is mostly impractical in an emergency department setting.

ACTIVE INTERNAL REWARMING

Active internal rewarming starts initially with warm parenteral fluids. Large volumes of IV fluids are essential during the rewarming process as vasodilation causes expansion of the intravascular space. It is at this stage, (Swiss Hypothermia Stage II), where cardiovascular instability may occur and the patient's heart rhythm may progress from bradycardia to atrial fibrillation.

The first step in an unconscious patient who has vital signs (Swiss Hypothermia Stage III) is endotracheal intubation to protect the airway and to oxygenate the patient with warmed, humidified oxygen by ET tube (40–50°C). Nasogastric tube and bladder catheter lavage with 500cc NS at 40°C usually follows. Although there is a risk that overstimulation of an unconscious, severely hypothermic patient with endotracheal intubation may trigger ventricular fibrillation, the minimal risk outweighs the obvious benefits. [13]

Rhythm deterioration into ventricular fibrillation and asystole (Swiss Hypothermia Stage IV) will force a change in management. Defibrillation should be attempted, but it may not be successful until the core temperature rises to greater than 30°C. Similarly, the hypothermic heart may be unresponsive to cardiovascular resuscitation medications.

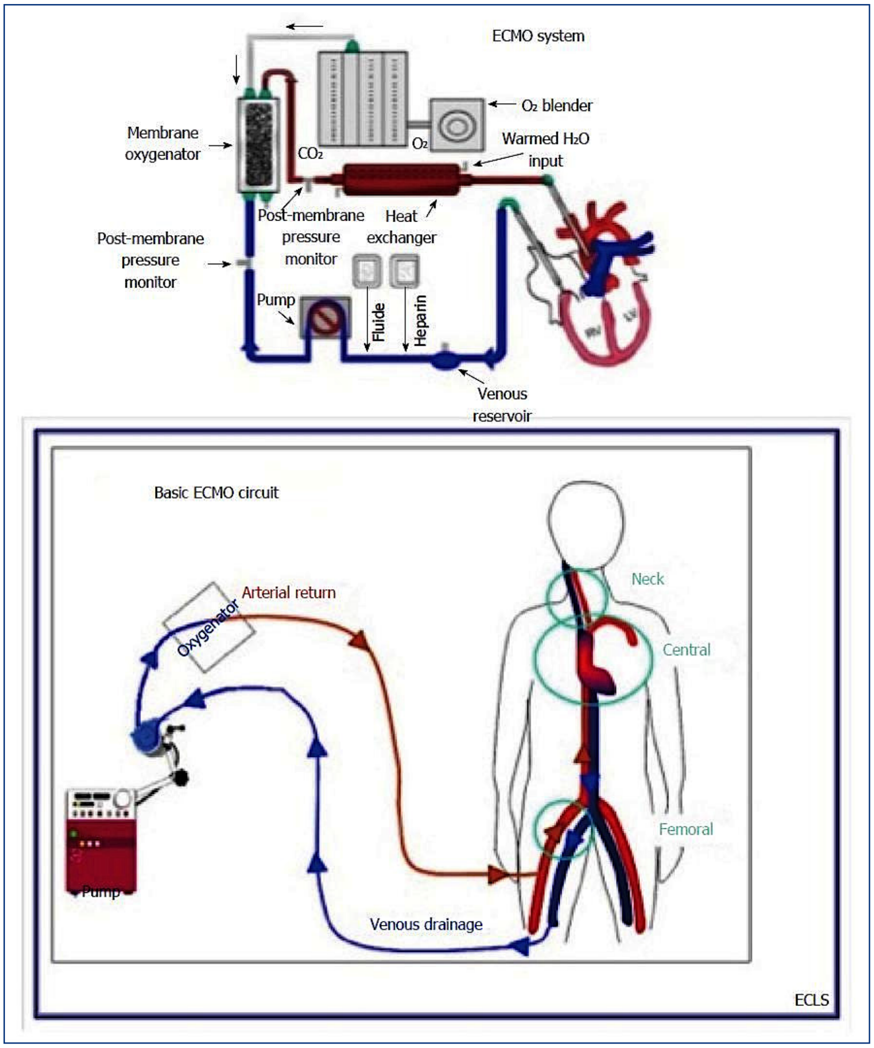
Centrally rewarming the heart helps prevent peripheral vasodilatation and cardiovascular collapse. Invasive treatments include delivery of warm fluids (1L NS at 40°C) via peritoneal lavage and/or via pleural lavage following bilateral tube thoracostomy, or with mediastinal irrigation after a thoracotomy. While case reports demonstrate successful resuscitations after prolonged CPR and active internal warming with peritoneal and pleural lavage, these techniques have shown relatively limited improvements in morbidity and mortality. [14,15,16]

Conventional techniques of rewarming are no longer the standard of care in level 1 trauma centers. Extracorporeal assisted warming (ECAR) has supplanted traditional methods of blood warming. ECAR, also called extracorporeal life support or ECLS, is a technology related to cardiopulmonary bypass (CPB), which was first utilized in 1953 by Gibbon to close an atrial septal defect in an 18-year-old. [17] ECAR has been successfully utilized in humans since 1967. [18,19] ECAR using extracorporeal membrane oxygenation (ECMO) provides vascular rewarming and augments oxygenation, ventilation, and cardiac output using portable mechanical circulatory support systems. Veno-arterial ECMO and CPB can raise body temperature by 6°C/hr and 9°C/hr, respectively, and have been shown to be much more effective than other rewarming techniques.[20] In one small subgroup analysis of patients suffering hypothermic cardiac arrest, survival among those warmed with conventional techniques was 14%, while those undergoing ECAR had an over 80% survival rate. [21] ECMO has numerous advantages over earlier cardiopulmonary bypass approaches to rewarming: 1) it is usually instituted using femoral cannulation in severe hypothermia under conscious sedation; 2) ECMO may be used for greater than a week whereas CPB is usually used for only a few hours; and 3) ECMO allows time for recovery of the lungs and heart in severe hypothermia and appears to reduce ischemia-reperfusion injury and prevents diastolic dysfunction. [22, 23]

Veno-arterial ECMO, usually with deoxygenated blood from the femoral vein going though the circuit with oxygenated blood being delivered to the femoral artery, has become the preferred ECMO method over veno-venous ECMO when there is severe hypothermia and refractory cardiac arrest (**see Figure 1**). Percutaneous vascular access can be obtained during traditional CPR via femoral cannulae connected to a circuit that pumps blood through an oxygenator and heat exchanger, then back into the patient. It facilitates chest wall access for ongoing CPR, allows for cardiovascular support with a stepwise, swift, controlled increase in the patient's body temperature, and it can be instituted rapidly using a groin incision in the emergency department. [23,24]

ECMO can be ended when the core temperature is greater than 37°C and there is a spontaneous, stable cardiac rhythm. It also can be terminated when there is failure to wean from ECMO, specifically when there is persistent asystole or refractory ventricular fibrillation and a core temperature of greater than 36°C. That patient is often defined as "warm and dead." Patients who suffer cardiac arrest prior to hypothermia and those who asphyxiate, as well as those who are frozen solid and have a non-compressible chest, have very poor outcomes regardless of the means used to rewarm, and they can be considered dead if they are without vital signs. While core temperature is not necessarily predictive of outcome, poor prognostic signs include potassium levels greater than 10 mmol/L in adults, and >12 mmol/L in children, severe acidosis (pH< 6.5), coagulopathy, as well as severe traumatic injury. [21,25]

Figure 1. Schematic illustrating components of an ECMO circuit



CASE REPORTS OF SEVERE HYPOTHERMIA

The lowest recorded temperature (13°C) with full recovery involved a sea immersion of a 7-year-old girl in Sweden in 2011. [26] There are numerous other case reports, with age ranges from 2½ to 65, showing successful resuscitation with neurologically intact survival from Swiss Stage Hypothermia Class IV and with no vital signs initially and extremely low core temperatures after prolonged CPR. All made full recoveries after treatment and rehabilitation, overcoming enormous odds against survival. The following are several case reports of patients with extremely low core temperatures, all believed to be incompatible with possible survival (<20°C).

Case 1: Core temperature of 13.7°C in cold water immersion in Norway

A 29-year-old female skier fell into a waterfall gully flooded by icy water. She was lifeless for approximately 45 minutes. CPR and endotracheal intubation were initiated shortly after rescue. She had 9 hours of resuscitation and rewarming, with ECMO needed for 5 days, but had a full recovery. [27]

Case 2: Core temperature of 16.9°C in avalanche burial in Poland

A 25-year-old woman was buried under 40 cm of snow in a vertical position for nearly 2 hours, but was able to breathe. She had a GCS of 11 upon extrication, and then developed ventricular fibrillation (VF) cardiac arrest. Three unsuccessful shocks were delivered and manual CPR was started and continued during evacuation, followed shortly thereafter with endotracheal intubation, with persistent VF. ECMO was implemented upon hospital arrival and the patient was successfully defibrillated after rewarming to 24.8°C. ECMO support was required for 91 hours. [28]

Case 3: Median core temperature of 18.4°C in seven boating accident victims in Denmark

Thirteen teenagers and two adults, ages 15–45, were immersed in 2°C seawater after a boating accident. One drowned, and seven patients had severe accidental hypothermic circulatory arrest. All were successfully resuscitated using a treatment approach that included extracorporeal rewarming, followed by intensive neuro-rehabilitation. Seven other hypothermic victims, with core temperatures as low as 23°C, did not suffer circulatory arrest and survived the accident with non-invasive management. All of the survivors who received extracorporeal rewarming made near-complete recoveries except for one who has severe cognitive dysfunction felt to be the result of asphyxia from near-drowning prior to the onset of severe hypothermia. [29]

Numerous case series and reviews support these anecdotes and case reports and conclude that patients with severe hypothermia and cardiac arrest treated with extracorporeal rewarming have successful resuscitation rates of up to 50%. [30,31,32] Although there are no reliable tools available to predict who eventually will survive to discharge after ECLS, these case series and a recent meta-analysis suggest that success rates might be even higher if certain exclusion criteria are used to determine candidates for prolonged CPR and ECMO, including: 1) asphyxia that precedes severe hypothermia with cardiac arrest and 2) severe hyperkalemia (>12 mEq/L), as extremely high potassium levels have been associated with a poor prognosis and death. [33,34] The highest recorded serum potassium in a successful severe hypothermia resuscitation is 11.8 mEq/L.[35] Age greater than 65 has also been used as an exclusion criteria in some Level 1 Trauma Centers.

CONCLUSIONS

While the data to support when to use ECMO may be limited, data suggest: 1) the duration of CPR does not predict outcome; and 2) patients with core temperatures below 14°C have been and can be successfully resuscitated. Therefore, aggressive management with CPR and rapid extracorporeal blood rewarming is indicated in any patient who has a cold exposure or cold water immersion and presents to an emergency department in severe accidental hypothermia with no vital signs and no lethal signs of injury, and has no evidence that asphyxia preceded the hypothermia. That patient should be seen as having the potential for a full recovery. Unless a patient has findings incompatible with life, then the axiom is true: "You're not dead until you're warm and dead."

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Author

John L. Foggle, MD, MBA, FACEP, Associate Professor, Department of Emergency Medicine, Alpert Medical School of Brown University.

Corresponding author

john_foggle@brown.edu