REVIEW ARTICLE

CURRENT CONCEPTS

Accidental Hypothermia

Douglas J.A. Brown, M.D., Hermann Brugger, M.D., Jeff Boyd, M.B., B.S., and Peter Paal, M.D.

From the Department of Emergency Medicine, University of British Columbia, Vancouver (D.J.A.B.), and the Department of Emergency Medicine, Mineral Springs Hospital, Banff, AB (J.B.) — both in Canada; the Institute of Mountain Emergency Medicine, European Academy of Bolzano, Bolzano, Italy (H.B.); and the Department of Anesthesiology and Critical Care Medicine, Innsbruck Medical University, Innsbruck, Austria (P.P.). Address reprint requests to Dr. Brown at the Department of Emergency Medicine, University of British Columbia, Vancouver General Hospital, 855 W. 12th Ave., Vancouver, BC V5Z 1M9, Canada, or at dbhypothermia@gmail.com.

This article was updated on January 10, 2013, at NEJM.org.

N Engl J Med 2012;367:1930-8.
DOI: 10.1056/NEJMra1114208

Copyright © 2012 Massachusetts Medical Society.

Accidental hypothermia (i.e., an involuntary drop in core body temperature to <35°C [95°F]) is a condition associated with significant morbidity and mortality.[1-4] Each year, approximately 1500 patients in the United States have hypothermia noted on their death certificate; however, the incidence of primary and secondary hypothermia and the associated morbidity and mortality remain unknown.[5] In a single tertiary care center, 14 different rewarming methods were used to treat 84 cases of accidental hypothermia,[3] which reflects the uncertainties about treatment and the potential for complications.[3] Certain treatment approaches are available only in specialized centers, and clarification is needed regarding the choice between transporting a patient to a specialized center and providing treatment locally. Existing recommendations do not include recent developments in rewarming methods nor do they assist with decisions regarding transportation.[6-8]

PRESENTATION

With cold exposure, the initial response of the body is to maintain a normal core temperature (approximately 37°C [99°F]) by means of active movement and involuntary shivering. Primary hypothermia occurs when heat production in an otherwise healthy person is overcome by the stress of excessive cold, especially when the energy stores of the body are depleted. Secondary hypothermia can occur in ill persons with a wide variety of medical conditions (Table 1), even in a warm environment. Death in patients with secondary hypothermia is often caused by the underlying condition rather than by hypothermia. In all types of hypothermia, consciousness, breathing, and circulation are initially intact but are impaired as the body cools.[10] Some patients with a core temperature of less than 28°C (82°F) engage in paradoxical undressing.[11] Atrial fibrillation is common when the core temperature is less than 32°C (90°F) and is not worrisome in the absence of other signs of cardiac instability.[9] The risk of cardiac arrest increases as the core temperature drops below 32°C, and increases substantially if the temperature is less than 28°C.[12]

DIAGNOSIS

Patients should be considered to have hypothermia if they have a history of cold exposure or a disease that predisposes them to hypothermia and if they have a cold trunk or a core temperature of less than 35°C (95°F) (Fig. 1). Hypothermia can be staged clinically on the basis of vital signs with the use of the Swiss staging system of hypothermia (stages HT I to HT IV)[10] (Table 2); this system is favored over traditional staging (mild, moderate, severe, and profound hypothermia)[12] whenever the

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

core temperature cannot be readily measured.

Measurement of the core temperature will confirm staging and inform transport and management decisions. Properly calibrated, low-reading thermometers are required but are not always available in the prehospital setting. The recorded temperature can vary depending on the body site, perfusion, and environmental temperature. In an intubated patient, insertion of a thermistor probe in the lower third of the esophagus is the preferred method.[9] Measurements obtained with the use of a proximally placed esophageal probe may be falsely elevated owing to ventilation with warmed gases. A thermistor probe in contact with the tympanic membrane accurately reflects brain temperature, provided that the ear canal is free of snow and cerumen and is well insulated against the environment.[14] Measurements obtained with the use of infrared cutaneous, aural, and oral thermometers are often inaccurate in patients with hypothermia. The bladder temperature may be falsely elevated during peritoneal lavage. Rectal probes should be inserted to a depth of 15 cm, but readings may lag behind core temperature during rewarming.[9] When accurate measurement of the core temperature is not feasible, as in some field settings, decisions regarding management should be based on the clinical Swiss staging system.

PREHOSPITAL TREATMENT

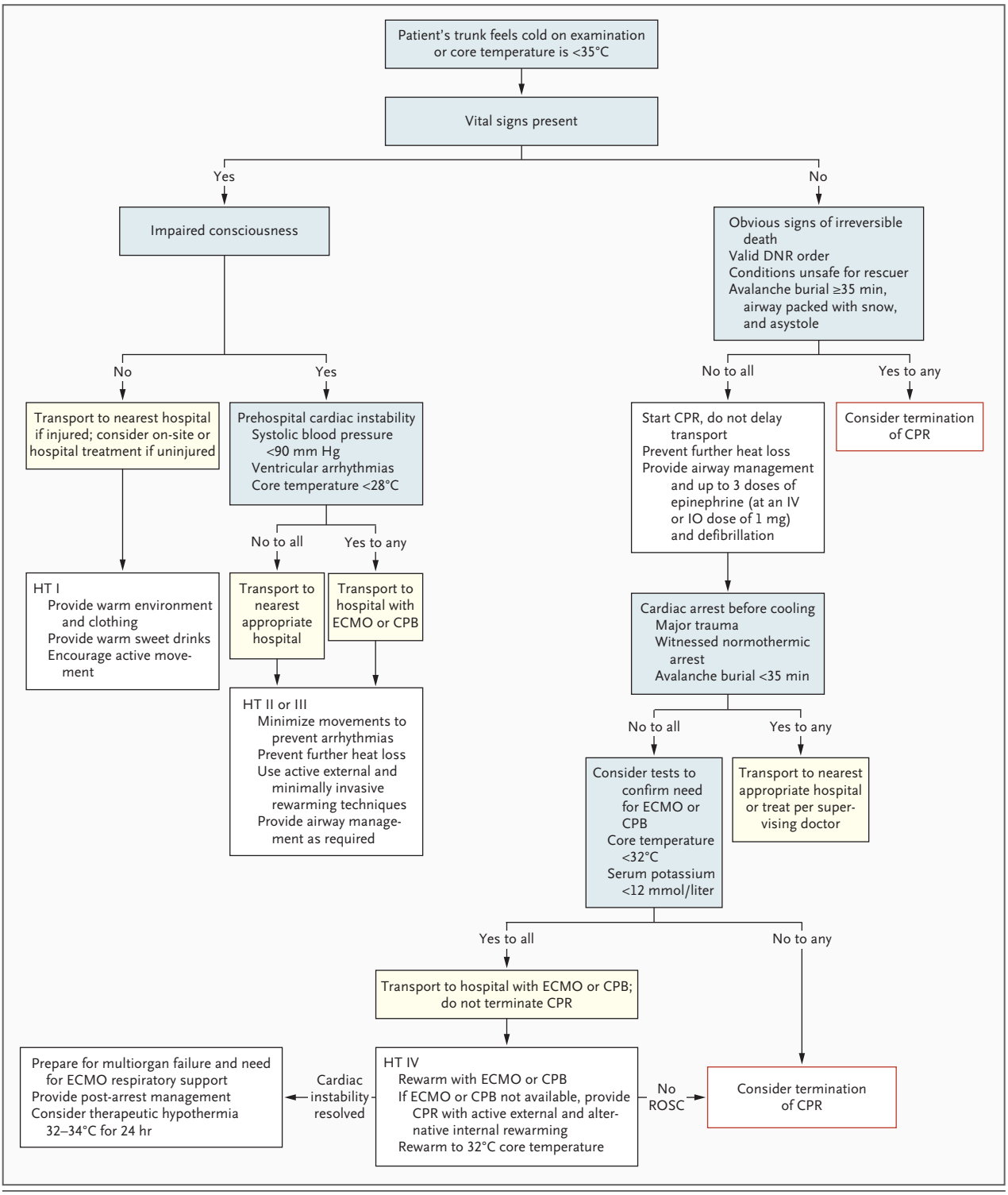
Priorities for prehospital treatment include careful handling of the patient, provision of basic or advanced life support, passive and active external rewarming, and transport to an appropriate facility. Detecting a pulse in a patient with hypothermia may be difficult, so signs of life and pulse should be checked carefully for 60 seconds. Persistent breathing or movement by the patient should prompt a strategy of watchful waiting, but if no signs of life are detected, then cardiopulmonary resuscitation (CPR) should be started.[7,8] Full-body insulation and rewarming should be provided for all patients as long as it does not impede CPR or delay transport.[7] For rewarming in the prehospital setting, only chemical, electrical, or forced-air heating packs or blankets provide a substantial amount of heat transfer (Table 3).[25,26] Advanced airway management[7] should be performed if indicated, since the risk of triggering a malignant arrhythmia is low.[13,27]

Table 1. Conditions Associated with Secondary Hypothermia.*

Impaired thermoregulation
Central failure
Anorexia nervosa
Cerebrovascular accident
Central nervous system trauma
Hypothalamic dysfunction
Metabolic failure
Neoplasm
Parkinson's disease
Pharmacologic effects
Subarachnoid hemorrhage
Toxins
Peripheral failure
Acute spinal cord transection
Decreased heat production
Neuropathy
Endocrinologic failure
Alcoholic or diabetic ketoacidosis
Hypoadrenalism
Hypopituitarism
Lactic acidosis
Insufficient energy
Extreme physical exertion
Hypoglycemia
Malnutrition
Neuromuscular compromise
Recent birth and advanced age with inactivity
Impaired shivering
Increased heat loss
Dermatologic disorder
Burns
Medications and toxins
Iatrogenic cause
Emergency childbirth
Cold infusions
Heat-stroke treatment
Other associated clinical states
Carcinomatosis
Cardiopulmonary disease
Major infection (bacterial, viral, parasitic)
Multisystem trauma
Shock

* Adapted from Danzl.[9]

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.



RESUSCITATION FLUIDS

Intravenous fluids should be warmed (38 to 42°C [100 to 108°F])[7,8,16] to prevent further heat loss. In a cold prehospital environment, intravenous fluids cool rapidly, and cold fluids may aggravate hypothermia.[8,16,28] A considerable volume of fluid is often required because of the volume loss with cold diuresis (renal-fluid wasting due to hypothermia-induced vasoconstriction and di-

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

Figure 1 (facing page). Management and Transport in Accidental Hypothermia.

HT I, HT II, HT III, and HT IV refer to the four stages of hypothermia as defined by the Swiss staging system.[10] To convert values for temperature to degrees Fahrenheit, multiply by 9/5 and add 32. Obvious signs of irreversible death include decapitation, truncal transection, decomposition of the whole body, and a chest wall that is not compressible (i.e., the whole body is frozen solid). Rigor mortis as well as fixed and dilated pupils may be present in patients with reversible hypothermia. Active external and minimally invasive rewarming techniques include placement of the patient in a warm environment; use of chemical, electrical, or forced-air heating packs or blankets; and parenteral administration of warm fluids (38 to 42°C [100 to 108°F]). A systolic blood pressure of less than 90 mm Hg is a reasonable prehospital estimate of cardiac instability, but for in-hospital decisions, the minimum sufficient circulation for a patient with a core temperature of less than 28°C (82°F) has not been defined. Therefore, it is not known at what point a patient with refractory cardiac instability should be transitioned to extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass (CPB). In remote areas, the transport adviser must balance the risk of increased transport time with the potential benefit of treatment in a center that can provide ECMO or CPB. For a patient with cardiac arrest in a remote area, the need for ECMO or CPB can be confirmed by measuring the serum potassium level at an intermediate hospital, ideally en route toward a center that can provide ECMO or CPB. When transfer to such a center is not feasible, active external and alternative internal rewarming techniques should be used. DNR denotes do not resuscitate, IO intraosseous, IV intravenous, and ROSC return of spontaneous circulation.

minished release of antidiuretic hormone) and vasodilatation during rewarming.[8] Warm crystalloid fluids should be administered on the basis of volume status and glucose, electrolyte, and pH measurements; resuscitation with a large volume of normal saline may aggravate acidosis, so alternative crystalloids should be considered. Vasopressors may be used to treat vasodilatory hypotension, but caution is required, owing to the potential for arrhythmia and the risk of peripheral-tissue perfusion, particularly in patients at risk for frostbite.[29]

TRANSPORT

Conscious, shivering patients (stage HT I) can be treated in the field if they are uninjured or transported to the closest hospital if rewarming is not possible in the field (Fig. 1 and Table 2). Patients with impaired consciousness (stage HT II, HT III, or HT IV) should be assessed for cardiac instability. Patients with stable circulation require active external and minimally invasive rewarming (placement in a warm environment; application of chemical, electrical, or forced-air heating packs or blankets; and administration of warm parenteral fluids) (Table 2) and should be taken to the closest hospital that can provide these measures. Patients with prehospital cardiac instability (e.g., systolic blood pressure of <90 mm Hg or ventricular arrhythmias),[9] those with a core temperature of less than 28°C (82°F), and those in cardiac arrest should be transported to a center capable of providing extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass, unless coexisting conditions (e.g., trauma) mandate transport to a closer facility.

Owing to the decrease in cerebral oxygen requirements with cooling,[8] survival without neurologic impairment may be possible even when it is necessary to perform CPR for hours. The longest reported duration of CPR with full neurologic recovery after extracorporeal rewarming is 190 minutes.[30] Survival after 390 minutes of CPR has been documented when rewarming with forced-air blankets and peritoneal lavage was used.[31] If the decision is made to stop at a facility where the serum potassium level can be measured, a hospital en route to a center that can provide ECMO or cardiopulmonary bypass should be selected. If the serum potassium level is higher than 12 mmol per liter (see discussion below), termination of CPR should be considered (Fig. 1). When the patient transport time will be considerable, the use of a mechanical chest-compression device should be considered, since it preserves the energy of the rescue crew, increases safety, and may improve the outcome.[32] The destination hospital should be contacted in advance to ensure that ECMO or cardiopulmonary bypass is available. In remote areas, the transport adviser must balance the risk of a longer transport time against the potential benefit of treatment in a center that can provide ECMO or cardiopulmonary bypass.

RESCUE COLLAPSE AND AFTERDROP

Rescue collapse is defined as cardiac arrest that is related to the extrication and transport of a patient with deep hypothermia (stage HT III).[2,4,21,22,31,33,34] Rescue collapse has been attributed to circulatory collapse due to hypovolemia, cardiac arrhythmias triggered by interventions (e.g., movement of the

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

Table 2. Staging and Management of Accidental Hypothermia.*

Stage	Clinical Symptoms	Typical Core Temperature†	Treatment
HT I	Conscious, shivering	35 to 32°C	Warm environment and clothing, warm sweet drinks, and active movement (if possible)
HT II	Impaired consciousness, not shivering	<32 to 28°C	Cardiac monitoring, minimal and cautious movements to avoid arrhythmias, horizontal position and immobilization, full-body insulation, active external and minimally invasive rewarming techniques (warm environment; chemical, electrical, or forced-air heating packs or blankets; warm parenteral fluids)
HT III	Unconscious, not shivering, vital signs present	<28 to 24°C	HT II management plus airway management as required; ECMO or CPB in cases with cardiac instability that is refractory to medical management
HT IV	No vital signs	<24°C	HT II and III management plus CPR and up to three doses of epinephrine (at an intravenous or intraosseous dose of 1 mg) and defibrillation, with further dosing guided by clinical response; rewarming with ECMO or CPB (if available) or CPR with active external and alternative internal rewarming

* Hypothermia may be determined clinically on the basis of vital signs with the use of the Swiss staging system.[10] CPB denotes cardiopulmonary bypass, CPR cardiopulmonary resuscitation, and ECMO extracorporeal membrane oxygenation.

† Measurement of body core temperature is helpful but not mandatory. The risk of cardiac arrest increases as the core temperature drops below 32°C and increases substantially if the temperature is less than 28°C.[12,13] To convert values for temperature to degrees Fahrenheit, multiply by 9/5 and add 32.

patient or central venous catheterization), and further cooling.[9,12,35]

Afterdrop is defined as continued core cooling after rescue, which has been documented in artificial cooling experiments or inferred through discrepancies between rectal and core temperatures. With the use of active external and minimally invasive rewarming and concurrent esophageal temperature measurement, afterdrop has not been reported.[15,16,36]

IN-HOSPITAL TREATMENT

In a patient with hypothermia and stable circulation, active external and minimally invasive rewarming is indicated (Table 2),[7,36] as well as treatment of any condition causing secondary hypothermia (Table 1). Given the increased risk of complications, such as hemorrhage or thrombosis, with invasive rewarming methods (e.g., body-cavity lavage, endovascular devices, and extracorporeal heating systems), as well as the absence of evidence that these methods improve the outcome, the best approach may be the use of active external and minimally invasive rewarming.[37] When selecting the rewarming method and rate (Table 3), clinicians should consider accessibility to an appropriate facility, local expertise, resources, and characteristics of the patient. When central venous access is required, it is important to keep the tip of the catheter (and guide wire) far from the heart in order to minimize the risk of arrhythmia.[9]

ECMO or cardiopulmonary bypass should be considered for patients with hypothermia and cardiac instability who do not have a response to medical management. At a core temperature of 28°C (82°F), oxygen consumption and the pulse rate are usually decreased by 50%,[9] but the minimum sufficient circulation has not been defined; therefore, it is not known at what point a patient with cardiac instability should undergo ECMO or cardiopulmonary bypass. The use of ultrasonography and near-infrared spectroscopy to visualize blood flow and assess cerebral oxygenation may assist with these decisions in the future.[38,39]

When signs of life and vital signs are absent (stage HT IV), there is consensus that treatment with ECMO or cardiopulmonary bypass is safe and efficient.[1,2,6-8,12,22,24,33,34,40-42] Among patients treated with ECMO or cardiopulmonary bypass, the rate of survival without neurologic impairment is 47 to 63%.[1,2,33,41] For patients with hypothermia of stage HT IV who are not treated with ECMO or cardiopulmonary bypass, limited data are available, but the survival rate is likely to be less than 37%.[13,16,43] The advantage of ECMO or cardiopulmonary bypass relates to the establishment of blood flow during rewarming. Support with ECMO has resulted in improved outcomes, as compared with traditional cardiopulmonary bypass,[24,41] probably owing to the high incidence of severe pulmonary failure after rewarming, which can be treated more efficiently with ECMO. If ECMO or cardiopulmonary bypass is not avail-

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

Table 3. Effectiveness of Rewarming Techniques.

Technique	Rewarming Rate	Indication
	°C/hr	
Without cardiac support		
Warm environment and clothing, warm sweet drinks, and active movement[9]	2 (dependent on metabolic rate)*	HT I
Active external and minimally invasive rewarming (warm environment; chemical, electrical, or forced-air heating packs or blankets; and warm parenteral fluids)[3,15-18]	0.1–3.4	HT II or HT III with cardiac stability
Peritoneal dialysis[19]	1–3	Uncertain
Hemodialysis[20]	2–4*	Uncertain
Thoracic lavage[21,22]	3*	HT IV when ECMO or CPB not available
Venovenous ECMO[23]	4*	Uncertain
With cardiac support		
Venoarterial ECMO[24]	6*	HT III with cardiac instability or HT IV
CPB[2]	9*	HT III with cardiac instability or HT IV when ECMO not available

* Value is approximate.

able and transport to a facility with these capabilities is not possible, circulation should be supported with CPR while the patient is rewarmed with a locally available, alternative internal rewarming technique (Table 3).[16,20,21,31] According to case reports, thoracic lavage has restored spontaneous circulation within 2 hours[21] and is a reasonable alternative rewarming technique when ECMO or cardiopulmonary bypass is not available.[7] In patients with a return of spontaneous circulation, multiorgan failure should be expected, and respiratory support with ECMO may be required. Standard management after cardiac arrest is indicated, and some experts recommend 24 hours of therapeutic hypothermia (32 to 34°C [90 to 93°F]), but evidence in support of this approach is lacking. If a patient with cardiac arrest due to hypothermia is rewarmed to a core body temperature that is higher than 32°C and asystole persists, irreversible cardiac arrest is very likely, and termination of CPR should be considered.

MODIFIED VERSUS STANDARD ADVANCED LIFE SUPPORT

The use of vasopressors in animal models of hypothermic cardiac arrest have had mixed results, with a small number of studies showing a benefit.[44] The guidelines of the European Resuscitation Council recommend a modified approach to advanced life support, consisting of up to three defibrillations, with epinephrine withheld until the core temperature is higher than 30°C (86°F) and with the interval between doses doubled until the core temperature is higher than 35°C (95°F).[8] These recommendations conflict with the American Heart Association guidelines, which state, "It may be reasonable to consider administration of a vasopressor during cardiac arrest according to the standard ALS [advanced life support] algorithm concurrently with rewarming strategies."[7] Hence, the administration of up to three doses of medication and defibrillation is likely to be a reasonable approach, with further dosing guided by the clinical response.[45]

SERUM POTASSIUM

Increased serum potassium levels can be caused by hypoxic and traumatic cell death, medications (e.g., depolarizing neuromuscular blockers), and a variety of medical conditions. A severely elevated serum potassium level is associated with nonsurvival and is considered a marker of hypoxia before cooling.[1,33,46] The highest recorded levels of serum potassium in patients with accidental hypothermia who were successfully resuscitated are 11.8 mmol per liter in a 31-month-old child,[42] 9.5 mmol per liter in a 13-year-old child,[47] 7.9 mmol per liter in a 34-year-old adult,[33] and 6.4 mmol per liter in an adult who survived burial in an avalanche.[48]

Some researchers recommend a potassium level

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

of 12 mmol per liter[49] or 10 mmol per liter[2,4,33,50] as the cutoff above which CPR is considered to be futile, with a cutoff of 8 mmol per liter in adults who have been buried in an avalanche.[7] We recommend that termination of CPR be considered when the potassium level is higher than 12 mmol per liter (Fig. 1), and we recommend consultation with the team providing ECMO or cardiopulmonary bypass when the potassium level is 10 to 12 mmol per liter. When the potassium level is less than 10 mmol per liter, survival without neurologic impairment may be possible, and CPR should be continued until the patient is rewarmed. Unfortunately, a low serum potassium level does not ensure survival.[1,4,7,33] Other biomarkers, such as lactate and pH levels, have been reported to have prognostic significance, although less consistently.[3,4,13]

ACCIDENTAL HYPOTHERMIA IN SPECIAL SITUATIONS

TRAUMA

Trauma, notably shock and cerebrospinal injury, destabilizes thermoregulation[9]; thus, patients with multiple traumas or with central nervous system trauma are prone to hypothermia. Hypothermia increases bleeding and transfusion requirements and may increase mortality.[51,52] Clotting-factor activity and platelet function are reduced with lowered temperature, causing a critical coagulopathy below 34°C (93°F).[53] Blood is warmed before laboratory testing; hence, hypothermia-induced coagulopathy is not measured.[52] Heparin-coated systems for cardiopulmonary bypass, which obviate the need for systemic heparinization, allow the rewarming of patients with severe trauma.[47]

AVALANCHE BURIAL WITHOUT VITAL SIGNS

The maximum reported cooling rate in a person who had been completely buried in an avalanche was 9°C (16.2°F) per hour.[17,34] With a burial time of less than 35 minutes, life-threatening hypothermia is unlikely, owing to insufficient cooling time, and trauma and hypoxia should be suspected as the cause if vital signs are absent.[7,8,29,46] If the burial time exceeds 35 minutes, the airway is packed with snow, and the patient is asystolic, hypoxia probably preceded hypothermia and CPR is unlikely to be beneficial. However, if the burial time is longer than 35 minutes and the airway is not blocked, severe hypothermia should be suspected and the patient should be treated accordingly (Fig. 1).[8,46,54] The core temperature can be used to estimate the burial time if it is unknown (i.e., a temperature of less than 32°C [90°F] correlates with a burial time of more than 35 minutes).[46]

DROWNING WITHOUT VITAL SIGNS

Persons who have been submerged in cold water may have a better outcome than those submerged in warm water.[55] If the patient's history indicates immersion in cold water (i.e., the body was exposed to cold water, but the patient was able to breathe) and it is likely that the body cooled before the onset of hypoxia and cardiac arrest (stage HT IV), survival without neurologic impairment may be possible,[40,56] and resuscitation should proceed (Fig. 1). If the history indicates submersion in cold water (i.e., the body was exposed to cold water, and the patient was unable to breathe) before cooling, the outcome may be worse.[1,33] The longest period of submersion that a person has survived without neurologic impairment was 66 minutes in a child who was 2.5 years old (the child's core temperature was 19°C [66°F]).[57]

OUTCOME

The lowest reported core body temperatures in patients with full neurologic recovery are slightly less than 14°C (57°F) in a case of accidental hypothermia[40] and 9°C (48°F) in a case of induced hypothermia.[58] A survey of patients with stage IV hypothermia at one center showed that organ failure was common 24 hours after admission, and among fatal cases of organ failure, the most common cause of death was pulmonary edema.[3] Patients with primary hypothermia and cardiac stability who have been treated with active external and minimally invasive rewarming have a rate of neurologically intact survival of approximately 100%,[16] whereas for patients with cardiac arrest treated with extracorporeal rewarming, the rate is approximately 50%.[1,2,33,41] With cardiac arrest, full recovery may be possible if hypoxia did not precede hypothermia, no serious underlying disease or trauma exists, and extracorporeal rewarming is used.[2,41] To aid in predicting outcomes for unusual presentations, we have provided summary data from important studies of stage III and IV accidental hypothermia in the Supplementary Appendix, available with the full text of this article at NEJM.org.

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

SUMMARY

Advances in the safety and availability of rewarming techniques have improved the prognosis for patients with hypothermia, especially in the case of patients with cardiac arrest who are treated with extracorporeal rewarming. Patients who have hypothermia without cardiac instability should be rewarmed with active external and minimally invasive rewarming techniques. Patients with cardiac arrest may survive without neurologic impairment if hypothermia was not preceded by a hypoxic event, if there is no serious underlying disease or trauma, and if extracorporeal rewarming is used. For patients with hypothermia and cardiac instability or cardiac arrest, ECMO may be the best treatment currently available and is preferable to cardiopulmonary bypass. Early transport to a facility with the necessary capabilities and selection of an appropriate rewarming technique have the potential to decrease complications and improve survival. Analyses from hypothermia registries and prospective trials are needed to improve treatment strategies.

No potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

We thank Bruce Brink, Ross Brown, Gordon Giesbrecht, Peter Mair, Ken Zafren, and the members of the International Commission for Alpine Rescue for contributing to the conception of the project; and Emily Procter of the EURAC Institute of Mountain Emergency Medicine, European Academy of Bolzano, for editing an earlier draft of the manuscript, as well as providing technical and artistic assistance.

REFERENCES

1. Silfvast T, Pettilä V. Outcome from severe accidental hypothermia in Southern Finland — a 10-year review. Resuscitation 2003;59:285-90.
2. Walpoth BH, Walpoth-Aslan BN, Mattle HP, et al. Outcome of survivors of accidental deep hypothermia and circulatory arrest treated with extracorporeal blood warming. N Engl J Med 1997;337:1500-5.
3. van der Ploeg GJ, Goslings JC, Walpoth BH, Bierens JJLM. Accidental hypothermia: rewarming treatments, complications and outcomes from one university medical centre. Resuscitation 2010;81:1550-5.
4. Mair P, Kornberger E, Furtwaengler W, Balogh D, Antretter H. Prognostic markers in patients with severe accidental hypothermia and cardiocirculatory arrest. Resuscitation 1994;27:47-54.
5. Baumgartner EA, Belson M, Rubin C, Patel M. Hypothermia and other cold-related morbidity emergency department visits: United States, 1995-2004. Wilderness Environ Med 2008;19:233-7.
6. Larach MG. Accidental hypothermia. Lancet 1995;345:493-8.
7. Vanden Hoek TL, Morrison LJ, Shuster M, et al. Part 12: cardiac arrest in special situations: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122:Suppl 3: S829-S861. [Errata, Circulation 2011; 123(6):e239, 2011;124(15):e405.]
8. Soar J, Perkins GD, Abbas G, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8: cardiac arrest in special circumstances: electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Resuscitation 2010;81:1400-33.
9. Danzl DF. Accidental hypothermia. In: Auerbach PS, ed. Wilderness medicine. 6th ed. Philadelphia: Mosby, 2012:116-42.
10. Durrer B, Brugger H, Syme D. The medical on-site treatment of hypothermia: ICAR-MEDCOM recommendation. High Alt Med Biol 2003;4:99-103.
11. Brändström H, Eriksson A, Giesbrecht G, Ängquist KA, Haney M. Fatal hypothermia: an analysis from a sub-arctic region. Int J Circumpolar Health 2012;71:1-7.
12. Danzl DF, Pozos RS. Accidental hypothermia. N Engl J Med 1994;331:1756-60.
13. Danzl DF, Pozos RS, Auerbach PS, et al. Multicenter hypothermia survey. Ann Emerg Med 1987;16:1042-55.
14. Walpoth BH, Galdikas J, Leupi F, Muehlemann W, Schlaepfer P, Althaus U. Assessment of hypothermia with a new "tympanic" thermometer. J Clin Monit 1994;10:91-6.
15. Steele MT, Nelson MJ, Sessler DI, et al. Forced air speeds rewarming in accidental hypothermia. Ann Emerg Med 1996; 27:479-84.
16. Kornberger E, Schwarz B, Lindner KH, Mair P. Forced air surface rewarming in patients with severe accidental hypothermia. Resuscitation 1999;41:105-11.
17. Putzer G, Schmid S, Braun P, Brugger H, Paal P. Cooling of six centigrades in an hour during avalanche burial. Resuscitation 2010;81:1043-4.
18. Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzinger M, Brugger H. Respiratory failure and spontaneous hypoglycemia during noninvasive rewarming from 24.7°C (76.5°F) core body temperature after prolonged avalanche burial. Ann Emerg Med 2012;60:193-6.
19. Vella J, Farrell J, Leavey S, Magee C, Carmody M, Walshe J. The rapid reversal of profound hypothermia using peritoneal dialysis. Ir J Med Sci 1996;165:113-4.
20. Sultan N, Theakston KD, Butler R, Suri RS. Treatment of severe accidental hypothermia with intermittent hemodialysis. CJEM 2009;11:174-7.
21. Plaisier BR. Thoracic lavage in accidental hypothermia with cardiac arrest — report of a case and review of the literature. Resuscitation 2005;66:99-104.
22. Althaus U, Aeberhard P, Schüpbach P, Nachbur BH, Mühlemann W. Management of profound accidental hypothermia with cardiorespiratory arrest. Ann Surg 1982;195:492-5.
23. Tiruvoipati R, Balasubramanian SK, Khoshbin E, Hadjinikolaou L, Sosnowski AW, Firmin RK. Successful use of venovenous extracorporeal membrane oxygenation in accidental hypothermic cardiac arrest. ASAIO J 2005;51:474-6.
24. Morita S, Inokuchi S, Yamagiwa T, et al. Efficacy of portable and percutaneous cardiopulmonary bypass rewarming versus that of conventional internal rewarming for patients with accidental deep hypothermia. Crit Care Med 2011;39:1064-8.
25. Lundgren P, Henriksson O, Naredi P, Björnstig U. The effect of active warming in prehospital trauma care during road and air ambulance transportation — a clinical randomized trial. Scand J Trauma Resusc Emerg Med 2011;19:59.
26. Hultzer MV, Xu X, Marrao C, Bristow G, Chochinov A, Giesbrecht GG. Pre-hospital torso-warming modalities for severe hypothermia: a comparative study using a human model. CJEM 2005;7:378.
27. Miller JW, Danzl DF, Thomas DM. Urban accidental hypothermia: 135 cases. Ann Emerg Med 1980;9:456-61.
28. Paal P, Beikircher W, Brugger H. Avalanche emergencies: review of the current

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.

situation. Anaesthesist 2006;55:314-24. (In German.)
29. Brugger H, Paal P, Boyd J. Prehospital resuscitation of the buried avalanche victim. High Alt Med Biol 2011;12:199-205.
30. Husby P, Andersen KS, Owen-Falkenberg A, Steien E, Solheim J. Accidental hypothermia with cardiac arrest: complete recovery after prolonged resuscitation and rewarming by extracorporeal circulation. Intensive Care Med 1990;16:69-72.
31. Lexow K. Severe accidental hypothermia: survival after 6 hours 30 minutes of cardiopulmonary resuscitation. Arctic Med Res 1991;50:Suppl 6:112-4.
32. Perkins GD, Brace S, Gates S. Mechanical chest-compression devices: current and future roles. Curr Opin Crit Care 2010;16:203-10.
33. Farstad M, Andersen KS, Koller ME, Grong K, Segadal L, Husby P. Rewarming from accidental hypothermia by extracorporeal circulation: a retrospective study. Eur J Cardiothorac Surg 2001;20:58-64.
34. Oberhammer R, Beikircher W, Hörmann C, et al. Full recovery of an avalanche victim with profound hypothermia and prolonged cardiac arrest treated by extracorporeal re-warming. Resuscitation 2008;76:474-80.
35. Giesbrecht GG, Steinman AM. Immersion in cold water. In: Auerbach PS, ed. Wilderness medicine. 6th ed. Philadelphia: Mosby, 2012:143-70.
36. Röggla M, Frossard M, Wagner A, Holzer M, Bur A, Röggla G. Severe accidental hypothermia with or without hemodynamic instability: rewarming without the use of extracorporeal circulation. Wien Klin Wochenschr 2002;114:315-20.
37. Taylor EE, Carroll JP, Lovitt MA, et al. Active intravascular rewarming for hypothermia associated with traumatic injury: early experience with a new technique. Proc (Bayl Univ Med Cent) 2008;21:120-6.
38. Rubio Á, Hakami L, Münch F, Tandler R, Harig F, Weyand M. Noninvasive control of adequate cerebral oxygenation during low–flow antegrade selective cerebral perfusion on adults and infants in the aortic arch surgery. J Card Surg 2008;23:474-9.
39. Kämäräinen A, Sainio M, Olkkola KT, Huhtala H, Tenhunen J, Hoppu S. Quality controlled manual chest compressions and cerebral oxygenation during in-hospital cardiac arrest. Resuscitation 2012;83:138-42.
40. Gilbert M, Busund R, Skagseth A, Nilsen PÅ, Solbø JP. Resuscitation from accidental hypothermia of 13.7 degrees C with circulatory arrest. Lancet 2000;355:375-6.
41. Ruttmann E, Weissenbacher A, Ulmer H, et al. Prolonged extracorporeal membrane oxygenation-assisted support provides improved survival in hypothermic patients with cardiocirculatory arrest. J Thorac Cardiovasc Surg 2007;134:594-600.
42. Dobson JAR, Burgess JJ. Resuscitation of severe hypothermia by extracorporeal rewarming in a child. J Trauma 1996;40:483-5.
43. Danzl DF, Hedges JR, Pozos RS. Hypothermia outcome score: development and implications. Crit Care Med 1989;17:227.
44. Schwarz B, Mair P, Raedler C, Deckert D, Wenzel V, Lindner KH. Vasopressin improves survival in a pig model of hypothermic cardiopulmonary resuscitation. Crit Care Med 2002;30:1311-4.
45. Wira CR, Becker JU, Martin G, Donnino MW. Anti-arrhythmic and vasopressor medications for the treatment of ventricular fibrillation in severe hypothermia: a systematic review of the literature. Resuscitation 2008;78:21-9.
46. Boyd J, Brugger H, Shuster M. Prognostic factors in avalanche resuscitation: a systematic review. Resuscitation 2010;81:645-52.
47. von Segesser LK, Garcia E, Turina M. Perfusion without systemic heparinization for rewarming in accidental hypothermia. Ann Thorac Surg 1991;52:560-1.
48. Locher T, Walpoth B. Differential diagnosis of circulatory failure in hypothermic avalanche victims: retrospective analysis of 32 avalanche accidents. Praxis 1996;85:1275-82. (In German.)
49. Brodmann Maeder M, Martin D, Balthasar E, et al. The Bernese Hypothermia Algorithm: a consensus paper on in-hospital decision-making and treatment of patients in hypothermic cardiac arrest at an alpine level 1 trauma centre. Injury 2011;42:539-43.
50. Schaller MD, Fischer AP, Perret CH. Hyperkalemia. JAMA 1990;264:1842-5.
51. Wang HE, Callaway CW, Peitzman AB, Tisherman SA. Admission hypothermia and outcome after major trauma. Crit Care Med 2005;33:1296-301.
52. Rajagopalan S, Mascha E, Na J, Sessler DI. The effects of mild perioperative hypothermia on blood loss and transfusion requirement. Anesthesiology 2008;108:71-7.
53. Watts DD, Trask A, Soeken K, Perdue P, Dols S, Kaufmann C. Hypothermic coagulopathy in trauma: effect of varying levels of hypothermia on enzyme speed, platelet function, and fibrinolytic activity. J Trauma 1998;44:846-54.
54. Brugger H, Durrer B, Adler-Kastner L, Falk M, Tschirky F. Field management of avalanche victims. Resuscitation 2001;51:7-15.
55. Tipton MJ, Golden FS. A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion. Resuscitation 2011;82:819-24.
56. Eich C, Bräuer A, Kettler D. Recovery of a hypothermic drowned child after resuscitation with cardiopulmonary bypass followed by prolonged extracorporeal membrane oxygenation. Resuscitation 2005;67:145-8.
57. Bolte RG, Black PG, Bowers RS, Thorne JK, Corneli HM. The use of extracorporeal rewarming in a child submerged for 66 minutes. JAMA 1988;260:377-9.
58. Niazi SA, Lewis FJ. Profound hypothermia in man: report of a case. Ann Surg 1958;147:264-6.
Copyright © 2012 Massachusetts Medical Society.

IMAGES IN CLINICAL MEDICINE

The *Journal* welcomes consideration of new submissions for Images in Clinical Medicine. Instructions for authors and procedures for submissions can be found on the *Journal*'s website at NEJM.org. At the discretion of the editor, images that are accepted for publication may appear in the print version of the *Journal*, the electronic version, or both.

The New England Journal of Medicine
Downloaded from nejm.org at HUNTINGTON MEMORIAL HOSPITAL on June 3, 2014. For personal use only. No other uses without permission.
Copyright © 2012 Massachusetts Medical Society. All rights reserved.