Accidental Hypothermia & Frostbite: Cold-Related Conditions

James J. O'Connell, MD
Denise A. Petrella, RN, CS, ANP
Richard F. Regan, PA-C

Mankind has struggled with injuries from the extremes of weather throughout history. While ancient physicians such as Hippocrates and Galen wrote extensively about hypothermia, most reports of cold injuries in the literature come from military history. Hannibal lost half of his army crossing the Alps in 218 B.C. During Napoleon's retreat from Moscow in the fall and winter of 1812, as many as 50,000 soldiers died of hypothermia. During the Great World Wars of the first half of the 20th century, ground troops on the march and in the trenches of Europe succumbed to the severe effects of the cold. High altitude frostbite was described in 1943, accounting for more injuries to heavy bomber crews in World War II than all other causes combined. And during the Korean War, 10% of the total US casualties were due to the cold.

Homeless persons who wander our urban cities and rural areas are vulnerable to the extremes of weather and exposure. Our goal in this chapter is to review how best to recognize, evaluate, and treat the common but preventable cold-related injuries of hypothermia and frostbite.

Hypothermia

During the twenty-year period from 1979-1998, hypothermia was the cause of death for approximately 700 persons annually in the USA, with half of these deaths attributed to extremely cold weather. Mortality rates in accidental hypothermia have ranged from 30-80%.

Hypothermia occurs not only during the bitter cold. Other important contributing factors include wind speed, moisture, alcohol, drugs, and the duration of exposure to the cold. Our worst case of hypothermia among Boston's homeless population occurred in early October several years ago, when a sunny day of 55°F (13°C) was followed by rain and a fall in temperature to 34°F (1.1°C) in the evening. Our patient's body temperature was 59°F (15°C), and he survived after undergoing cardio-pulmonary bypass therapy at Massachusetts General Hospital.

Definition and Pathogenesis

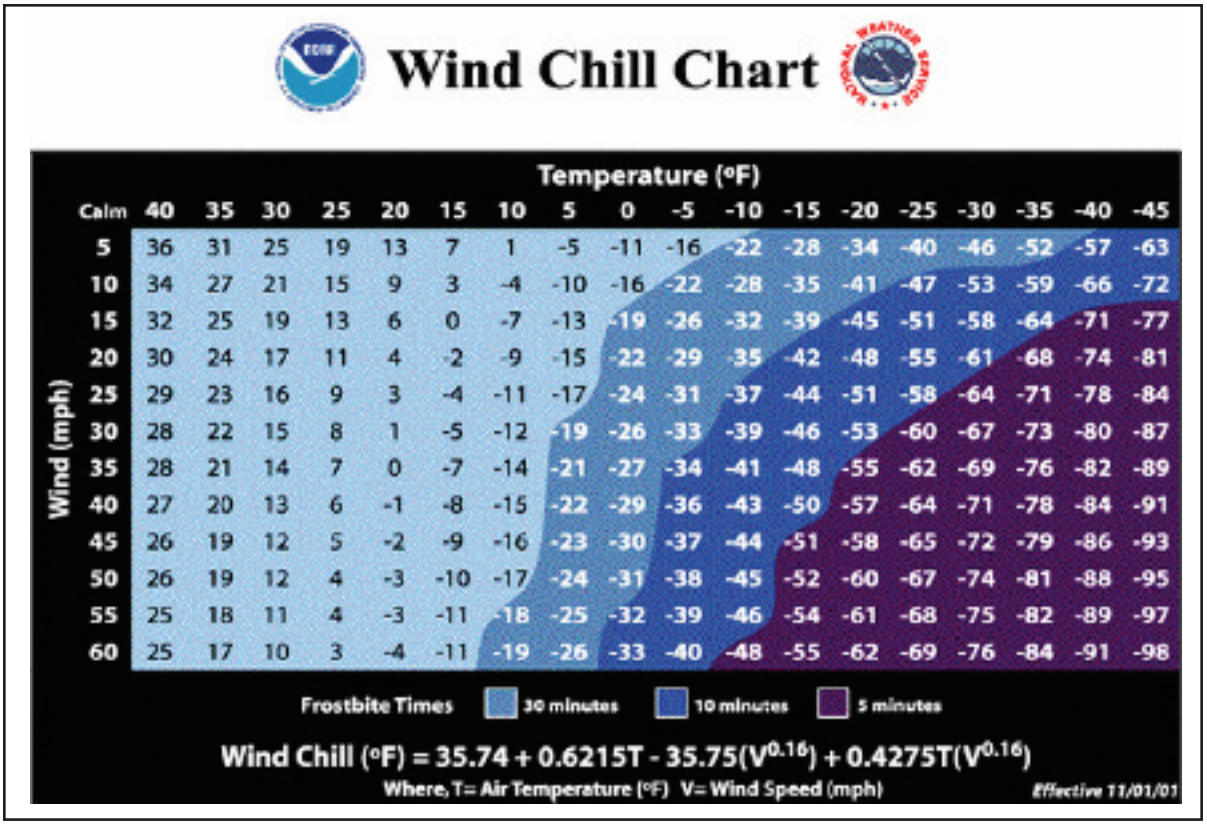
Hypothermia is defined as a core body temperature below 95°F (35°C), and can be helpfully categorized as follows:

- mild hypothermia: 90°-95°F (32°-35°C)
- moderate hypothermia: 82°-90°F (28°-32°C)
- severe hypothermia: below 82°F (28°C)

The body generates heat through the metabolism of food and water, the work of the muscles, and certain chemical reactions. The body's heat is lost primarily through the skin and lungs in four important ways:

- *radiation* accounts for 65% of heat loss.

Early Frostbite of the Hand. This man left the Accident Floor at Boston Medical Center on a clear January morning with a temperature of 18°F and no wind. We found him one hour later with frostbite of his fingers. This picture was taken several days later. The blisters are bloody, and he eventually lost two fingers. Photo by James O'Connell MD



Wind Chill Chart

Wind (mph) \ Temperature (°F)	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
Calm																		
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes | 10 minutes | 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

Wind Chill Chart. Courtesy of the National Weather Service Forecast Office

The most glaring example is the uncovered head, which can dissipate up to 50% of the body's heat;

- *conduction* is the direct transfer of heat to a nearby object that is cooler than the body. This is usually only a small fraction of the heat lost by the body, but wet clothing causes a 20-fold increase in heat loss from the body, and submersion in cold water increases the heat loss by 32 times;
- *convection* occurs when the warm layer of heat near the body is lost by the movement of air, and the degree of heat loss is dependent on the speed of the wind. For example, a wind of 12 mph increases heat loss by 5 times;
- *evaporation* is the heat lost when liquids are converted to gas. The evaporation of water cools the body at the rate of 0.6 kcal per gram. This occurs through sweating and respiration, which together account for about 20% of the body's heat loss.

When hypothermia occurs, cell membranes allow intracellular fluid to leak out, and enzymes begin to malfunction. Electrolyte imbalance occurs, especially hyperkalemia (increased potassium in the bloodstream). Water inside and outside the cells begins to crystallize, and cell death results. The hypothalamus attempts to stimulate heat production through shivering and by increasing catecholamine and adrenal activity. To minimize heat loss, blood flow to the peripheral tissues is reduced by vasoconstriction.

Causes of Hypothermia

In a study of 85 consecutive patients with hypothermia at San Francisco General Hospital, underlying infection or sepsis was the primary cause in 33 (39%) and alcohol ingestion in 27 (32%). Exposure accounted for only 9 cases. Almost half (49%) of these cases of hypothermia resulted in death.

Thus the differential diagnosis of hypothermia is important to keep in mind. In addition to environmental exposure, several medical conditions can either cause or increase the risk of hypothermia, including: sepsis, hypoglycemia, neuromuscular disease, malnutrition, hypothyroidism, and adrenal insufficiency. Some medications can hinder the body's response to the cold and increase the risk of hypothermia, such as beta-blockers (e.g. propranolol or Inderal™), clonidine (Catapres™), meperidine (Demerol™), and neuroleptics (e.g. haloperidol or Haldol™). Alcohol is particularly dangerous because it not only alters the ability to feel the cold

Table 1: Factors that predispose to hypothermia
Environment
Time of year
Ambient temperature
Wind chill
Water chill
Behavior
Inadequate or wet clothing
Immersion
Prolonged exposure
Lack of fitness
Fatigue
Inadequate shelter and heat
Drugs
Alcohol
Nicotine
Opiates
Barbiturates
Benzodiazepines
Tricyclic antidepressants
Phenothiazines
Decreased thermoregulation
Age extremes
Central nervous system trauma
Stroke
Wernicke's encephalopathy
Burns
Sepsis
Acute myocardial infarction
Chronic renal failure
Pancreatitis
Neoplasms
Decrease heat production
Hypothyroidism
Hypoglycemia
Hypoadrenal states
Anorexia

and impairs judgment, but also causes peripheral vasodilation that further enhances the loss of heat.

Symptoms and Clinical Presentation

Everyone caring for homeless persons in shelters and on the streets should become familiar with the signs and symptoms of hypothermia:

- *mild hypothermia*, 90°-95°F (32°-35°C): increased heart rate and respiratory rate, hyperventilation, difficulty walking, slurred speech, impaired judgment, pronounced shivering, and frequent urination due to the "cold diuresis";
- *moderate hypothermia,* 82°-90°F (28°-32°C): the pulse drops, breathing becomes shallow with a slowed respiratory rate, shivering stops, the reflexes are slowed, and the person can become very confused and disoriented. Paradoxical undressing may occur. Cardiac arrhythmias are common;
- *severe hypothermia*, below 82°F (28°C): hypotension, slow pulse, pulmonary edema, coma, ventricular arrhythmias (including ventricular fibrillation). The heart can stop beating completely (asystole or "flat line" on the EKG).

Diagnostic Evaluation

Early recognition is critical. Clinicians caring for homeless persons should maintain a high degree of suspicion for hypothermia whenever the weather turns cold. The astute clinician needs to be alert to any of the signs and symptoms described above. Most standard thermometers are not accurate below 93°F (34°C) and are not suitable for measuring the degree of hypothermia. The tympanic thermometers that are commonly used are unproven to date for assessing hypothermia.

The physical examination can be perplexing, especially in moderate and severe hypothermia. Patients can appear dead: comatose, the blood pressure difficult to hear, respirations shallow to absent, the pulse not palpable, the pupils dilated, deep tendon reflexes absent, and when shivering stops (usually around 85°-89°F or 30°-32°C) the muscle tone increases and can appear similar to rigor mortis. Helpful findings are signs of frostbite, sites

Plantar Frostbite. This elderly man slept for several cold nights in an abandoned car in South Boston. He has severe frostbite involving the toes and soles of his feet. Photo by James O'Connell MD

Table 2: Interesting Hypothermia Facts

The half life of morphine is 1.5 hours at 98.6°F (37°C), but 36 hours at 77°F (25°C).

Pancreatitis is seen in about 50% of patients after they are warmed.

At core temp of 86°F (30°C), urine flow is three times normal.

With every 1°C drop in core body temperature:
- blood flow in the brain decreases 7%
- viscosity of blood increases 5%
- hematocrit increases 2%

Advance life support protocols, especially defibrillation, may be ineffective when the core temperature is less than 86°F (30°C).

of insulin or drug injection, and evidence of head trauma. The rule is to assume that no one is dead "until warm and dead"; thus resuscitation efforts should continue until the body temperature reaches 90°-95°F (32°-35°C).

The medical complications of hypothermia are legion, and space limits our discussion. Laboratory studies should look for evidence of lactic acidosis, rhabdomyolysis, and bleeding disorders. Conduction is very slow through the cold myocardium, and the EKG can show prolongation of all intervals and a variety of arrhythmias, from atrial fibrillation to ventricular fibrillation. The characteristic elevation of the J point, called the Osborn wave, is a classic sign of hypothermia. Seen best in leads V2-V5, the height of the Osborn wave roughly corresponds to the degree of hypothermia.

Management

The management of hypothermia begins with an initial evaluation and, if indicated, CPR should be initiated. 911 should be called immediately. The prevention of further heat loss is paramount, such as removing wet clothing and covering the head with a hat.

Rewarming the person is the next step. However, the appropriate techniques are somewhat controversial and a subject of much debate. The three basic techniques are as follows:

- *Passive external rewarming.* This is the treatment of choice for mild hypothermia. After wet clothing is removed, the person should be covered with blankets or other insulation. This will limit further heat loss and allow the patient's body to generate heat and increase the core body temperature. Persons with mild hypothermia should be able to generate heat through shivering.
- *Active external rewarming.* This means the utilization of warm blankets, warm baths, or heating pads to warm the patient. This is generally sufficient in moderate hypothermia, as well as for anyone who has failed to respond to passive external rewarming. There is a risk with this process which is called "afterdrop". When both the extremities and the trunk are warmed together, the cold blood which has been pooled in the extremities returns to the central circulation and can cause a drop in the core temperature. At the same time, peripheral vasodilation begins as the extremities are warmed, and this flow of blood away from the core can cause a sudden drop in blood pressure and result in dangerous arrhythmias. For these reasons, rewarming of the trunk should routinely be undertaken before the extremities.
- *Active internal rewarming.* Several treatment modalities are available for rewarming persons with severe hypothermia, and the most common include irrigation of the pleural and peritoneal spaces with warm fluids, hemodialysis, and cardiopulmonary bypass. These techniques can be augmented by the use of warm humidified oxygen, warm intravenous fluids, and bladder irrigation with warm saline.

CPR should be started on site and continued during transportation for anyone found with severe hypothermia and cardiac arrest. Since the cold has a protective effect on the brain during anoxia, attempts at rewarming should wait until after arrival at the hospital. Remember that persons with core temperatures as low as 57°F (14°C) have survived.

Hypothermia may be an insidious cause of death among homeless persons that is often overlooked. Mild hypothermia causes poor coordination and clumsiness, stiff joints and muscles, and confusion; this can lead to stumbling and falling as well as poor judgment that may cause accidents, drownings, and falls that result in death. The sequence of events leading to death can often be complex, and hypothermia should always be considered when the weather is cold.

Frostbite

Frostbite refers to local tissue freezing and injury that can occur with any degree of hypo-

The Devastation of Frostbite.
This young man slept in the snow and sustained frostbite of all toes. These pictures show the course of his ordeal over a very painful 18 months at McInnis House. Photos by James O'Connell MD

(clockwise)
1. Two Weeks. The toes are blackened and necrotic with marked eschar. Viable tissue is likely beneath this eschar, but the line of demarcation between dead and living tissue is not known at this time. The current standard of care is to wait for auto-amputation in order to preserve as much of the toes as possible.
2. One Month. The wound is clean and dry without evidence of infection. The eschar is beginning to separate from the viable tissue beneath.
3. Three Months. The eschar and necrotic tissue of the great toe are now separating in the process of auto-amputation. The metatarsal head is visible, and surgery was necessary to cover the exposed bone.
4. Eighteen Months. Resolution of the frostbite and the remaining viable toes.

thermia. "Frostnip" refers to cold-related tingling and numbness that is not associated with any tissue damage. The hands and feet are the most common sites (almost 90% of the time), followed by the ears, nose, cheeks, and penis. While most texts note that the very young and the elderly are at highest risk, frostbite is most common in adults from 30-50 years old. In extensive studies from the Scandinavian countries, frostbite has been associated with wet and improper clothing, a history of previous hypothermia or frostbite, wound infection, diabetes, and smoking. All of these factors are commonplace among persons struggling with homelessness, and clinicians need to be vigilant for frostbite during the cold weather.

Mechanisms of Tissue Injury

We now have a better understanding of the pathways that cause injury in frostbite. Three processes - *tissue freezing, hypoxia, and the release of inflammatory mediators* - occur at essentially the same time.

- The freezing of the tissue is accompanied by the formation of ice crystals that damage the cell membranes. Water then leaks out of the cells, leading to cellular dehydration and death.
- Peripheral blood vessels constrict in response to the cold, depriving the tissue of oxygen. The flow of blood in the capillaries ceases, leading to clotting or thrombosis within small arterioles and venules. This further exacerbates the hypoxia in the tissue.
- Inflammatory mediators are released in response to all of these insults: local tissue damage, hypoxia, and thrombosis. The most potent are the prostaglandins PGF2

Table 3. Treatment of Frostbite
Patients with frostbite injuries are admitted to the hospital
On admission, the affected area(s) will be rapidly rewarmed in circulating warm water, 104-108°F (40-42°C) for 15-30 minutes. Patients presenting 24 hours after injury will not be rewarmed.
On completion of rewarming, the affected parts will be treated as follows: a. debride white blisters and apply topical aloe vera (e.g. Dermaide Aloe Cream™) every 6 hours to prevent further synthesis of thromboxane; b. bloody or hemorrhagic blisters should be left intact and aloe vera (e.g. Dermaide Aloe Cream™) applied every 6 hours; c. splint and elevate the injured area; d. tetanus prophylaxis; e. IV narcotics as needed; f. ibuprofen 400 mg every 12 hours orally; g. IV penicillin G 500,000 units every 6 hours for 48-72 hours to decrease potential streptococcal infection during the edema phase; h. daily hydrotherapy for 30-45 minutes at 104°-108°F (40°-42°C); i. avoid smoking, which causes vasoconstriction and can further aggravate the cold injury.

Adapted from Heggers JP, McCauley RL, Phillips LG. Cold-induced injury: frostbite. In: Herndon DN, ed. Total Burn Care. Philadelphia: WB Saunders; 1996: 408.

and thromboxane A2. These cause further vasoconstriction, depriving the tissue of yet more oxygen, and also cause platelet aggregation, exacerbating the thrombosis. The peak time for the release of these mediators is during the rewarming process.

The goal of treatment is to reverse or limit each of these processes. Rewarming can stop the tissue from freezing and reverse the vasoconstriction, while medications can block the release of the inflammatory mediators.

Diagnosis and Clinical Manifestations

The American College of Surgeons categorizes frostbite by the degree of tissue injury. This determination cannot be made until after rewarming, and sometimes it may take up to two weeks before the extent of damage is known.

- *First degree frostbite* is superficial and characterized by numbness, swelling, and a central white area surrounded by redness.
- *Second degree frostbite* is also superficial and accompanied by clear or cloudy blisters that develop over the first 24 hours after the injury. These blisters are usually surrounded by redness and swelling.
- *Third degree frostbite* involves bloody or hemorrhagic blisters that are a sign of deeper tissue injury. These blisters blacken and slough off about two weeks after the injury.
- *Fourth degree frostbite* affects muscle and bone and causes necrosis, gangrene, and eventual loss of tissue. The long term sequellae are devastating, including amputation, chronic pain, and osteoarthritis.

Many clinicians prefer only two classes of frostbite: superficial (first and second degree) and deep (third and fourth degree). This practical approach acknowledges that the treatment of frostbite is the same for all degrees until the demarcation between the viable and non-viable tissue occurs 3-6 weeks later.

Regardless of the degree of injury, most persons with frostbite experience similar initial symptoms. The involved area feels cold and numb and can become clumsy. With rewarming, the numbness gives way to a severe throbbing pain that can last for many weeks. Some patients also describe a sensation of an "electric shock" running through the affected area. The frostbitten area often develops sensory loss and an increased cold sensitivity which can last for years. Arthritis and chronic neuropathic pain can occur after deep frostbite in an area.

Treatment

The goal of treatment is to salvage tissue by reversing the effects of tissue freezing, hypoxia, and the release of inflammatory mediators. The three phases of treatment for frostbite are described in this section.

Pre-Thaw Phase

The aim of this initial phase is to avoid thawing and re-freezing, which magnifies tissue damage. Wet clothing should be removed from the affected

area. In urban areas with hospital availability, do not try to thaw in the field. The affected area should be wrapped in lose clothing and splinted to avoid trauma. Try to minimize movement of the area. Never rub or massage the area. Do not use heating pads or heat lamps because the frostbitten area is without sensation, and serious burns can easily occur.

Hospital Care Phase

Rapid rewarming is the cornerstone of treatment in this phase. The affected area should be warmed in water at 104°-108°F (40°-42°C). Mild antibacterials such as hexachlorophene or providine-iodine may be added. The rewarming process can be very painful, especially if this is done too quickly. Narcotics should be used for pain control as needed. Rewarming is complete when the skin becomes pliable and has a reddish-purple color.

Once rewarming is completed, continued immediate treatment is crucial to minimize tissue damage. Unfortunately, many homeless persons present for care of frostbite long after the initial damage and after the affected area has been warmed. No treatment protocol has been uniformly endorsed for the immediate treatment of frostbite after rapid rewarming. Many clinicians have adapted aspects of McCauley's protocol:

- debride white blisters, and apply topical aloe vera (e.g. Dermaide Aloe Cream™) every 6 hours to prevent further synthesis of thromboxane;
- bloody or hemorrhagic blisters should be left intact and aloe vera (e.g. Dermaide Aloe Cream™) applied every 6 hours;
- splint and elevate the injured area;
- tetanus prophylaxis;
- IV narcotics as needed;
- ibuprofen 400 mg every 12 hours orally;
- IV penicillin G 500,000 units every 6 hours for 48-72 hours to decrease potential streptococcal infection during the edema phase;
- daily hydrotherapy for 30-45 minutes at 104°-108°F (40°-42°C);
- avoid smoking, which causes vasoconstriction and can further aggravate the cold injury.

Early surgery is not indicated for the treatment of frostbite unless a fasciotomy is required to treat a compartment syndrome.

Early Frostbite.
(top)
BHCHP nurse practitioner Denise Petrella noted early frostbite on the toes of a man who came to the shelter clinic with a cold. He was admitted to McInnis House for care.
(middle)
Improvement at one week.
(bottom)
Resolution at two weeks.
Photos by James O'Connell MD

Post-Thaw Care Phase

The goal of this phase is two-fold: 1) to prevent secondary infection and 2) to support the homeless patient through a painful period of difficult medical decisions and great psychological stress, especially for those with severe frostbite who await the possible auto-amputation of digits or fingers.

In severe frostbite, an eschar forms in 9-15 days that is hard, black, and leathery. Over time (usually 22-45 days) the underlying tissue demarcates, and the viable tissue begins to separate from the non-viable eschar.

Patients should be monitored carefully for purulent drainage, which can be a sign of cellulitis or

a deeper infection of the bone called osteomyelitis. Wound care is needed for the shallow ulcers caused by blister formation. At our Barbara McInnis House in Boston, we have found that a thin coat of silver sulfadiazine cream (Silvadene Cream™) with a clean dressing twice each day protects and quickly dries the wound.

Severe frostbite can cause a very painful peripheral neuropathy. Narcotics are usually required for pain control, but with time these can be tapered if other neuropathic pain medications such as gabapentin (Neurontin™) are effective.

Amputation is often the most vexing problem, primarily because of the difficulty in predicting the severity of underlying injury. There is much wisdom to the adage: "freeze in January, amputate in July." In our experience at McInnis House, most fingers and toes that have suffered severe frostbite will mummify and autoamputate in 3-6 weeks, but some have taken far longer. To avoid this prolonged and stressful period of watching and waiting, there is considerable hope that certain imaging techniques will be able to accurately measure the extent of damage within the first week or two of injury. The use of technetium scintigraphy and MRI are among the possible future approaches, and the goal remains to maximize stump length while guiding early surgical intervention.

The complications of frostbite include residual pain, cold and heat intolerance, hyperhydrosis (increased sweating in the area), atrophy of the skin, and pigment changes.

We have seen a broad range of these complications at McInnis House, where we have admitted over 100 persons with frostbite over the past decade. One patient complained bitterly of severe "phantom pain" in the left foot for several months after losing three toes to frostbite. We initially suspected drug-seeking, but he underwent surgical sympathectomy in which several sympathetic nerves were severed. He almost immediately stopped asking for further pain medication. Several years later he returned to McInnis House with another episode of frostbite and lost several more toes during a six-month admission. He again suffered intense pain, which resolved when he underwent a new procedure called spinal cord stimulation. In this operation, an electrode is placed directly in the spine and a wire tunneled under the skin to a transducer. This gentleman is now able to directly stimulate the spine whenever the pain occurs, and this has replaced all of his previous pain medication.

Summary

Accidental hypothermia can be a life-threatening condition that affects virtually every organ system in the body. Hypothermia is defined as a body temperature below 95°F (35°C).

Hypothermia does not occur only during the bitter cold. Other important contributing factors include the wind speed, moisture, alcohol and other drugs, and the duration of exposure to the cold.

Several risk factors can cause homeless and other people to be more susceptible to hypothermia, including malnutrition, underlying infection, low blood sugar, neuromuscular disease, and certain medications.

Early recognition of hypothermia is very critical, and the treatment includes resuscitation and rewarming. Anyone with hypothermia should be brought to the hospital as soon as possible.

Frostbite is cold-induced tissue injury that usually affects the hands and feet, but can also involve the ears, cheeks, nose, and penis.

Frostbite can be superficial or deep. Deep frostbite can result in the amputation of fingers or toes or other affected areas.

The best treatment of both frostbite and hypothermia is prevention. Wear a hat and gloves in the cold, as well as layered clothing. Remember that frostbite occurs much more rapidly on windy and wet days. ■

Frostbite Medication List

Generic	Brand Name	Cost
sulfadiazine cream	Silvadene	$
aloe vera	Dermaide Aloe Cream	$
gabapentin	Neurontin	$$$$

References

American College of Surgeons, Committee on Trauma. *Advanced Trauma Life Support.* Chicago, IL: American College of Surgeons; 1997.

Centers for Disease Control and Prevention. Hypothermia-related deaths - Philadelphia, 2001, and United States, 1999. *MMWR* 2003;52(5):86.

Heggers JP, McCauley RL, Phillips LG. Cold-induced injury: frostbite. In: Herndon DN, ed. *Total Burn Care.* Philadelphia: WB Saunders; 1996:408.

Mechem CC. Accidental hypothermia. UpToDate, 2004. http://www.uptodate.com

Morris DL, Chambers HF, Morris MG, Sande MA. Hemodynamic characteristics of patients with hypothermia due to occult infection and other causes. *Annals of Internal Medicine* 1985;102:153-157.