Chapter 30

COLD STRESS

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INTRODUCTION

Cold is a physical hazard that has historically caused significant morbidity and mortality among military personnel. Since the ancient times of Xenophon and Hannibal, soldiers have succumbed to the effects of cold-related injuries, resulting in thousands of deaths during war.[1] Cold weather injuries (CWIs), however, are not exclusive to military operations during wartime but affect peacetime training as well. One study over a 52-month period at a hospital in Wurzburg, Germany, found that a majority of cold injuries occurred during general field training, and another study of the Israeli military found rates of CWI from routine training and duties to be twice that of combat.[2,3]

With advances in education, training, and equipment, rates of CWI have been significantly reduced. During World War I, rates of CWI from British soldiers declined from 33.9 to 3.8 cases per 1,000 person-years after the implementation of educational programs.[4] Similar findings of significant reductions in total CWI rates were observed in US Army personnel between 1980 and 1999.[5]

Cold injuries can be classified into three main categories:

1. freezing cold injuries,
2. nonfreezing cold injuries (NFCIs), and
3. hypothermia.

Freezing cold injuries and NFCIs are generally localized to the extremities of exposed skin. Freezing cold injuries may also be referred to as cold/dry or frostbite injuries, and NFCIs may be referred as cold/wet injuries. In contrast, hypothermia refers specifically to an abnormally low core body temperature. Figure 30-1 diagrams the different types of CWI.

PHYSIOLOGY

Body core temperature is the summation of heat production internally and heat gains and losses from the external environment. While heat can be gained from the environment via radiation, conduction, and convection, exposure to cold environments results in heat loss. Body core temperature is controlled by the preoptic area of the anterior hypothalamus, which regulates two core functions in regard to cold exposure, namely, peripheral vasoconstriction and shivering. Peripheral vasoconstriction, initiated in response to reduced skin temperatures, concentrates the blood in the internal organ structures, away from the surface of the body, thereby increasing tissue insulation and conserving heat. Shivering helps increase heat production through involuntary muscle contraction, resulting in increased metabolic heat production. Shivering can increase the metabolic rate 2- to 5-fold.[6] There is also an initial associated increase in the respiratory and heart rates. However, if the body core temperature continues to decrease, the metabolic, respiratory, and heart rates will decrease.

Although peripheral vasoconstriction occurs initially, continued cold exposure will lead to alternating cold-induced vasodilation (CIVD) in order to intermittently conserve dexterity and function in the extremities through periodic rewarming.[7] Furthermore, prolonged cold exposure results in cold diuresis and decreased fluid volume as blood is shunted centrally.

Minor physiologic acclimatization to the cold can occur, and generally manifests in three patterns: habituation, metabolic acclimatization, and insulative acclimatization, depending on the nature of the cold exposure.[8] Unfortunately, the physiological adjustments to chronic cold exposures are slower to develop, less pronounced, and less practical in relieving thermal strain and preventing cold injury compared to heat acclimatization.

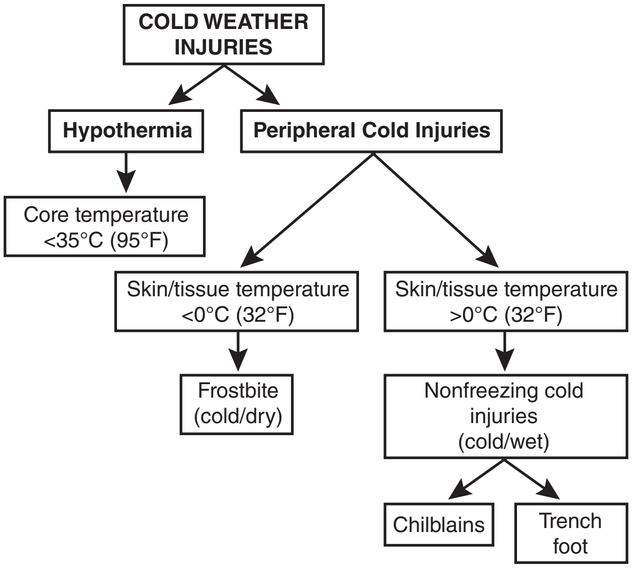

Figure 30-1. Types of cold injuries.
Reproduced from: US Department of the Army. *Prevention and Management of Cold-Weather Injuries*. Washington, DC: DA; 2005: 41. Technical Bulletin MED 508.

Due to the increased metabolic demand to maintain body core temperature homeostasis, work in cold environments requires an additional 10% to 15% more calories.[9]

Also, a unique phenomenon occurs during immersion in cold water, which triggers the diving reflex, involving an acute bradycardic response.[10] With colder water, the bradycardia becomes more pronounced.[11]

TEMPERATURE MEASUREMENTS

Several key components are important for evaluating cold exposures, including body core temperature and wind chill temperature (WCT) index. Generally, body core temperature is measured by a low-reading rectal thermometer. Measuring body core temperature at other sites, including sublingual, temporal, and axillary, results in inaccurate readings and is not recommended.[12] However, in the hospital, an esophageal temperature probe is the preferred instrument to monitor core temperatures.[13]

Ambient temperatures should be measured by thermometers capable of measuring temperatures down to at least -40°C (-40°F). Furthermore, the WCT index helps determine the risk of cold injury by estimating the relative cooling ability from the combination of air temperature and wind velocity. Additionally, although natural winds may be low, riding in open vehicles or standing near propeller- or rotor-generated winds can expose individuals to dangerous wind chill and should be taken into consideration. However, there is no risk of frostbite when the ambient air temperature is above 0°C (32°F), even if the WCT is below freezing. Similarly, wet skin will not freeze when the air temperature is above 0°C (32°F).[9] However, wet skin exposed to temperatures below 0°C (32°F) will freeze faster than dry skin.

Altitude must also be considered when planning operations. At higher elevations, winds are usually stronger, and the air temperature is usually lower. In general, with every 1,000 feet above the site at which the temperature is measured, the air temperature is 2°C (3.6°F) cooler.[9]

EXPOSURE GUIDELINES

General

In general, suitable thermometry should be available when environmental temperatures reach below 16°C (60.8°F). When air temperature falls below -1°C (30.2°F), the dry bulb temperature should be measured and recorded at least every 4 hours. Warning and safety briefings should also be provided, especially when temperatures drop below -7°C (19.4°F).

For a single, occasional cold exposure, a decrease in body core temperature no lower than 35°C (95°F) is permissible. Although clinical signs and symptoms of hypothermia may manifest even above this temperature, continuous, vigorous shivering should be taken as a dangerous sign, and removal from the cold exposure or recovery measures should be implemented immediately.

Body Protection and Insulation

When air temperature is below 4°C (39.2°F), whole-body protection, including adequate insulated dry clothing, should be provided. Furthermore, continuous cold exposure to unprotected skin such as the ears and face should not be permitted without adequate protection when the equivalent WCT is below -32°C (-26.5°F). Work should be modified or suspended if adequate dry clothing is not available. When clothing becomes wet, it should be changed immediately. Sweating is an important consideration because clothing appropriate for resting cold exposure may lead to wet skin and subsequent increased heat loss during physical work.

Hand Protection and Insulation

Protective measures should be established for the hands, particularly if manual dexterity is needed for work. At air temperatures of -17.5°C (0°F) or less, the hands should be protected by insulated gloves or mittens. If fine work with bare hands is required for more than 10 to 20 minutes in an environment below 16°C (60.8°F), adequate measures to maintain the warmth of extremities should be implemented. Additionally, tools should have appropriate protection. For instance, metal handles should be covered by thermal insulating material at temperatures below -1°C (30.2°F). Anti-contact gloves should also be employed to prevent contact frostbite.

Special precautions should be taken for workers dealing with evaporative liquids (eg, gasoline, alcohol, cleaning fluids) or liquefied gases (eg, liquid natural gas, liquid oxygen, liquid nitrogen). In the event of a spill, appropriate protective equipment from both the cold and the spilled agent must be employed.

External Equipment

External equipment, such as shielding material for the work area, can limit effects of wind and rain that can contribute to cold-induced injuries. If work is performed in outdoor environments below 4°C (39.2°F), external equipment should be utilized. Moreover, heated warming shelters (eg, tents, cabins) should be available nearby for periodic use at regular intervals if work is to be performed continuously when the equivalent WCT is below -7°C (19.4°F). Progressive signs or symptoms of cold injury should prompt immediate return to warming shelters.

Other Safety Considerations

Workers should be instructed in proper safety techniques prior to working in cold environments. This includes knowledge of first aid rewarming measures, appropriate personal protective equipment and clothing, adequate nutrition and hydration, signs and symptoms of cold injuries, and safe working practices. At temperatures below -12°C (10.4°F) equivalent chill temperature, constant supervision should be maintained, such as employing a "buddy" system. In addition, work intensity and exertion should be controlled to prevent workers from sweating heavily, which can accelerate heat loss.

Depending on factors in the cold environment such as precipitation, wind, and sunlight, eye protection should also be worn to protect the eyes not only from physical debris (eg, blowing snow and ice crystals) but also from ultraviolet (UV) light. Prolonged work in a snowy environment without eye protection can lead to photokeratitis, also known as snow blindness, caused by UV rays directly from the sun or indirectly from reflected rays of sunlight off the snow and ice, which can cause eye pain, blurred vision, headache, and temporary vision loss. Treatments for photokeratitis are listed in Exhibit 30-1.

EXHIBIT 30-1

TREATMENT FOR PHOTOKERATITIS (SNOW BLINDNESS)

Topical cycloplegic drops
- 1% cyclopentolate
- 2–5% homatropine
- 0.25% scopolamine

Ophthalmic antibiotics
- erythromycin
- bacitracin
- polymyxin B/bacitracin

Topical ophthalmic nonsteroidal anti-inflammatory drugs
- diclofenac
- ketorolac
- 0.5% tromethamine

Oral analgesics
- ibuprofen
- oxycodone

Data sources: (1) Jacobs DS. Photokeratitis. *UpToDate*. Sep 30, 2016. http://www.uptodate.com/contents/photokeratitis?source=machineLearning&search=snowblindness&selectedTitle=1~11&sectionRank=1&anchor=H7#H7. Accessed May 8, 2017. (2) Weaver CS, Terrell KM. Evidence-based emergency medicine. Update: do ophthalmic nonsteroidal anti-inflammatory drugs reduce the pain associated with simple corneal abrasion without delaying healing? *Ann Emerg Med*. 2003;41(1):134–140.

COLD INJURIES

Freezing Cold Injuries

Freezing injuries generally encompass damage to localized tissue when the local skin or tissue temperature falls below 0°C (32°F). Prolonged exposure to subzero temperatures and the resulting peripheral vasoconstriction can directly and indirectly lead to reversible and potentially irreversible damage. Multiple studies indicate that tissue damage can result from the following effects: intracellular and extracellular ice formation, cell dehydration and shrinkage, abnormal intracellular electrolyte concentrations, thermal shock, denaturation of lipid-protein complexes, production of inflammatory markers, and capillary structure damage.[9,14] As with other cold injuries, wind velocity can play a significant role in the development of freezing injuries, particularly when the ambient air temperature is already below zero. (As previously mentioned, there is no risk of freezing injuries when the ambient air temperature is above 0°C [32°F] even if the WCT is below freezing.[9]) Peripheral vasoconstrictive medications as well as nicotine use can increase susceptibility to freezing injuries. There is a 30% higher incidence of peripheral cold injuries in heavy smokers (two to three packs per day), likely secondary to reduction in the CIVD response from nicotine.[9]

Epidemiology

In the United States, no formal reporting system exists for freezing injuries. However, analysis of subgroup populations including the military have been analyzed. In the US military, of the 19 cases of CWI of service members serving in Operation Enduring Freedom and Operation Iraqi Freedom between 2001 and 2009, only two were from freezing injuries, one of which required surgical intervention.[15] A review of CWI among soldiers in Alaska revealed that the majority of freezing injuries were either first- or second-degree frostbite or superficial freezing injuries.[16] In the study of Israeli Defense Forces, of the 136 CWIs reported between 1994 and 2001, less than 5% were from freezing injuries.[3]

Classification and Clinical Features

Freezing injuries have traditionally been categorized into a four-tiered system, but some researchers and organizations (eg, the Wilderness Medicine Society) have proposed a two-tiered approach for simplicity, especially for field use. Both systems are described below. Most freezing injuries are described in the context of frostbite. Frostnip, another associated term, refers to the mildest form of freezing injury to the skin, sometimes categorized in conjunction with first-degree frostbite.

Four-tiered system. The traditional four-tiered approach ranges from first-degree frostbite (the least severe) to fourth-degree frostbite (the most severe).

Figure 30-2. Second-degree frostbite of the left foot. Full recovery will take weeks to months.
Reproduced from: Burr RE. Environmental medicine: heat, cold, and altitude. In: Kelley PW, ed. *Military Preventive Medicine. Mobilization and Deployment.* Vol 1. Washington, DC: Borden Institute; 2003: Figure 19-11.

1. First-degree frostbite is caused by a relatively short-duration exposure to cold air or direct physical contact with a cold object resulting in a partial thickness skin injury that spares deep structures. First-degree frostbite presents with mild erythema, edema, and hyperemia at the site of injury. Although mild pain and desquamation may accompany first-degree injuries, recovery is complete without scarring.
2. Second-degree frostbite produces a complete thickness skin injury sparing subcutaneous structures (Figure 30-2). However, with a full thickness injury, vesicles and bullae may form within 12 to 24 hours. Similar to first-degree frostbite, there is no permanent tissue loss; however, pain, numbness, cold sensitivity, and hyperhidrosis may occur.
3. Third-degree frostbite includes injuries produced by second-degree frostbite but also damages subcutaneous structures. Skin may appear black and hard. Generalized edema is common, and care should be taken to observe for potential compartment syndrome. Vesicles and bullae are similarly formed as in second-degree frostbite, but may be hemorrhagic versus filled with clear fluid. Once healing begins, ulcerations are produced with resulting scarring. Pain may be burning, aching, throbbing, or shooting and last up to a month.
4. Fourth-degree frostbite further damages deeper subcutaneous structures, potentially including muscles, tendons, or bones. Due to this extensive damage, mobility in the region is unlikely. Even with rewarming, mobility may be limited by the damage. Although some damage may be reversible, dry gangrene can occur, resulting in mummification within 5 to 10 days and possibly auto-amputation. To evaluate the severity of frostbite injuries if there is a concern for subcutaneous tissue damage, technetium 99m bone scan is the preferred diagnostic modality and can help guide surgical intervention.[17]

Two-tiered system. The two-tiered approach is divided into superficial and deep freezing injuries. Superficial freezing injuries will not result in tissue loss, whereas deep freezing injuries will result in tissue loss. Superficial freezing injuries essentially comprise the first-degree and second-degree frostbite injuries, and deep freezing injuries encompass the third-degree and fourth-degree frostbite injuries (Table 30-1).

TABLE 30-1

CLASSIFICATION OF FREEZING COLD INJURIES AND ASSOCIATED SIGNS

Superficial	Deep
First degree	**Third degree**
• Partial thickness freezing • Mild erythema, edema, hyperemia • No scarring	• Full thickness and subcutaneous freezing • Potential compartment syndrome • Scarring may occur
Second degree	**Fourth degree**
• Complete thickness freezing • No subcutaneous structures involved • Vesicles and bullae	• Full thickness and subcutaneous freezing • Involves muscles, tendons, or bones • Gangrene and mummification possible

Treatment

Regardless of the severity of the freezing injury, initial management should include removing the patient from the cold environment. Once rewarming is initiated, the patient should not be reexposed to the cold because thawing and refreezing can lead to more tissue damage. For mild frostbite cases, thawing can occur at room temperature. However, for more severe cases and when in the field, the decision about whether to rewarm or not may be difficult. A general guideline is that if the transport time to a medical facility is within 2 hours, the risks posed by thawing and refreezing are greater than the risk of delaying field treatment.[9]

The definitive treatment for frostbite is rapid rewarming in water. The ideal water temperature is between 36° and 42.2°C (96.8°–108°F).[18,19] Because the risk of infection is increased with more severe freezing injuries, an antiseptic solution (eg, hexachlorophene, povidone-iodine) may be added to the rewarming bath. In addition, analgesics and sedatives should be considered because rewarming can be extremely painful.[20] After thawing is complete, the injured site should be kept clean, dry, and protected from additional trauma. Furthermore, a tetanus booster should be provided if the patient is not currently up to date, and prophylactic antibiotics (eg, penicillin) should be considered if severe skin edema occurs (edema has been associated with inhibition of the skin's own streptococcicidal properties).[21] Early surgical intervention is not recommended, even with severe fourth-degree frostbite injuries, because some recovery may still occur without surgery.[9]

Adjuvant therapies have been shown to have efficacy in treating freezing injuries. Nonsteroidal anti-inflammatory drugs such as ibuprofen inhibit inflammatory reactions and pain, and have been shown to decrease tissue loss.[14] Prostaglandin E_1, which has been shown to reduce digital amputation rates, has several functions, including dilation of arterioles and venules, reduction in capillary permeability, suppression of platelet aggregation, and activation of fibrinolysis.[22] Other vasodilators including reserpine, pentoxifylline, and buflomedil have shown evidence of decreasing tissue loss as well.[23–25] Low-molecular-weight dextran has also been shown to reduce tissue damage in animal models.[26] Use of adjuvant therapies should be guided by a medical professional trained in their uses.

Nonfreezing Cold Injuries

NFCIs occur from prolonged exposures (12 hours to 4 days) to near freezing temperatures, generally between 0° and 15°C (32°–59°F).[27–29] Maximal peripheral vasoconstriction occurs at 15°C (59°F), and a further decrease in temperature to 10°C (50°F) results in CIVD, where periods of vasodilation interrupt the vasoconstriction that occurs at cold temperatures to help maintain some degree of perfusion to local tissue.[14] Despite the periods of CIVD, tissue damage occurs from the prolonged periods of vasoconstriction, resulting in damage to the endothelium and surrounding tissue from oxygen deprivation. In one study involving cold-water immersion of the fingers, subjects with weaker CIVD had higher risk of local cold injuries.[30]

Epidemiology

Accurate incidence rates of NFCI even among the military are difficult to determine because the condition often goes unrecognized. The clinical manifestations of NFCI are also often less dramatic than with freezing injuries. However, because NFCIs occur under milder environmental conditions, they likely occur more frequently than frostbite.[3] Among the Israeli Defense Forces in an 8-year period, the majority of 66 peripheral cold injuries were NFCI, specifically trench foot.[3] At the same time, reports in the US military have documented frostbite as the most common cold injury, possibly reflecting underdiagnosed NFCI.[31]

Classification

NFCI consists of two main categories, trench foot and chilblains (also called pernio or kibe). Trench foot occurs when tissue, most commonly of the feet, is exposed to cold temperatures for more than 12 hours. Chilblains, on the other hand, can occur within a few hours of exposure to the bare skin. Generally, these NFCIs occur in conjunction with wet environments.

Clinical Features

The initial clinical presentation of NFCI is similar for chilblains and trench foot. However, chilblains refers only to superficial damage, and it resolve without sequelae after rewarming (Figure 30-3). Clinically, there are four stages in the injury and recovery process for NFCI[9,14,32,33]:

1. Stage 1 occurs during the cold exposure, when local anesthesia and loss of proprioception occur. Due to intense vasoconstriction, tissue will initially be erythematous, then change to a paler color, and eventually turn white. If the NFCI is milder, as in cases of chilblains, pruritus can be present as well.
2. Stage 2, the prehyperemic phase, follows the removal of the cold exposure and immediate rewarming. Lasting anywhere from a few hours to a few days, this stage presents with tissue color change from white to mottled pale blue. Edema may also set in; however, if intermittent rewarming occurs, the edema is less severe. Peripheral pulses may also be absent, and capillary refill may be sluggish. Generally, pain is uncommon at this stage.
3. Stage 3, the hyperemic phase, is characterized by the body's attempt to increase perfusion to the affected region. Lasting anywhere from a few days to a few months, this stage is characterized by hot, erythematous, and flushed skin.[34] Peripheral pulses become bounding; however, capillary refill may remain prolonged. The anesthesia from prior stages begins to resolve, and significant pain ensues. In addition, the affected region may become hyperalgesic, and edema with potential vesicles and bullae may form, which can be blood-filled. Muscle weakness may also be apparent.
4. Stage 4, the posthyperemic phase, lacks obvious physical signs, but may last anywhere from a few weeks to years.[32,35] The inflammatory response with increased reperfusion observed in stage 3 diminishes, and due to the tissue damage, temperature regulatory mechanisms of the skin may be disrupted. The skin can experience temperature sensitivity, particularly to the cold. Furthermore, pain typically transitions to dull aches, and numbness may persist at more distal sites. Hyperhidrosis is also observed, which may contribute to recurrent fungal infections. More severe findings include contractures from deposition of fibrous scarring as well as gangrene from necrotic tissue and secondary infections.

Figure 30-3. Chilblains of the feet can be pruritic and painful. Reproduced from: Burr RE. Environmental medicine: heat, cold, and altitude. In: Kelley PW, ed. *Military Preventive Medicine. Mobilization and Deployment.* Vol 1. Washington, DC: Borden Institute; 2003: Figure 19-14.

Treatment

Removal of the cold exposure and wet, constrictive clothing is the primary management goal. For immediate field management of NFCI, covering the affected area with loose, warm, dry clothing during evacuation is also important. Specific protocols for treating more severe NFCI are not well defined in the literature, but continued monitoring of peripheral perfusion, providing analgesics for pain control, and potentially using calcium channel blockers (eg, nifedipine) or tricyclic antidepressants (eg, amitriptyline hydrochloride) may provide a degree of benefit.[9]

TABLE 30-2

ESTIMATED SURVIVAL TIME IN COLD WATER

Water Temperature °C	Water Temperature °F	Approximate Survival Time
20	68	10 h
15	59	3–6 h
10	50	2–5 h
5	41	1–3 h
0	32	< 90 min

Data sources: (1) Hayward JS, Eckerson JD, Collis ML. Thermal balance and survival time prediction of man in cold water. *Can J Physiol Pharmacol*. 1975;53(1):21–32. (2) Molnar GW. Survival of hypothermia by men immersed in the ocean. *J Am Med Assoc*. 1946;131(13):1046–1050.

Accidental Hypothermia

Accidental hypothermia is defined as an involuntary drop in the core body temperature below 35°C (95°F). It develops when the sustained heat loss to the environment exceeds heat production. Although hypothermia can occur in extremely cold environments, below-freezing temperatures are not necessary to develop the condition. Effects from factors including wind chill, water immersion, rain, and sweating may significantly contribute to hypothermia, even in milder temperatures. Particularly when the skin is exposed to water for prolonged periods, such as in the case of water immersion (Table 30-2) or wet clothing from rain or sweating, hypothermia can occur rapidly. Heat loss secondary to conduction can occur up to 5 times faster with wet clothing and up to 25 times faster with water immersion.[36] In addition, effects of alcohol, certain medications, and medical conditions can further predispose individuals to hypothermia.[37]

Epidemiology

The burden of accidental hypothermia, a preventable condition, is demonstrated by the mortality among the US civilian population. Between 1979 and 2002, an average of 689 persons per year died from hypothermia-related causes.[38] The incidence of hypothermia-related deaths increased between 1999 and 2011, averaging 1,301 deaths per year.[39]

Historically, the military has also suffered significant fatalities due to hypothermia, as mentioned previously. However, even within the last 30 years, the military remained susceptible to hypothermia-related casualties and deaths both in training and combat. For instance, in 1995, a class of US soldiers in Ranger School training in the swamps of Florida suffered from hypothermia, eventually resulting in four fatalities.[40] In the study of cold-weather injuries in military service members during Operation Enduring Freedom and Operation Iraqi Freedom from 2001 to 2009, 17 hypothermia cases were identified without any fatalities.[15] The Israeli study identifying CWIs in the Israeli Defense Forces between 1994 and 2001 revealed that 10% of cold injuries from combat were hypothermia-related, whereas 71% of cold injuries from training activities were hypothermia-related, compared to peripheral injuries.[3]

Classification

Accidental hypothermia is classified in several ways. Hypothermia can be classified by how it is induced and the relative time frame of induction. These categories include acute (immersion), submersion, subacute, and subchronic.[9]

- Acute (immersion) hypothermia: induced by partial or full immersion when conductive heat losses far exceed heat production (eg, falling through ice into cold water). Initially, the cold induces an initial hyperventilation (with risk of water aspiration) as well as a sudden fall in blood pressure. Heat loss can be minimized by limiting movement and huddling. Self-rescue is possible, but the longer the duration of immersion, the more difficult self-rescue will be.
- Submersion hypothermia: total submersion of the body in ice-cold water. This is more prevalent when young children fall through ice; water aspiration is more likely in this situation than with acute immersion. However, successful resuscitation has been achieved even after 45 to 60 minutes of submersion.
- Subacute hypothermia: exposures less severe than cold water immersion. Examples include prolonged exposure to cold air with wind, rain, and physical exertion. Subacute hypothermia develops over hours or several days.
- Subchronic hypothermia: prolonged exposure to cold temperatures, occurring over days to weeks. Examples include isolated soldiers in survival situations and the malnourished elderly in the civilian population.

Hypothermia can also be classified based on the corresponding body core temperature. Most staging categories include mild, moderate, and severe, while

TABLE 30-3

HYPOTHERMIA STAGING WITH PHYSIOLOGIC CHANGES ASSOCIATED WITH CORE TEMPERATURE

	Core Temperature		
Stage	°C	°F	Description
Mild	35.0	95.0	Maximal shivering, increased blood pressure
	34.0	93.2	Amnesia, dysarthria, poor judgment, behavior change
	33.3	91.4	Ataxia, apathy, cold diuresis
Moderate	32.0	89.6	Stupor
	31.0	87.8	Shivering ceases
	30.0	86.0	Cardiac arrhythmias, decreased cardiac output, insulin ineffective
	29.0	84.2	Unconsciousness, pupils dilate
Severe	28.0	82.4	Ventricular fibrillation likely, hypoventilation, paradoxical undressing[1]
	27.0	80.6	Loss of reflexes and voluntary motion
	26.0	78.8	Acid-based disturbances, no response to pain
	25.0	77.0	Reduced cerebral blood flow, loss of cerebrovascular autoregulation
	24.0	75.2	Hypotension, bradycardia, pulmonary edema
	23.0	73.4	No corneal reflexes, areflexia
	19.0	66.2	Electroencephalographic silence
	18.0	64.4	Asystole
	15.2	59.3	Lowest infant survival from accidental hypothermia[2]
	13.7	56.7	Lowest adult survival from accidental hypothermia[3]

1. Brandstrom H, Eriksson A, Giesbrecht G, Angquist KA, Haney M. Fatal hypothermia: an analysis from a sub-arctic region. *Int J Circumpolar Health*. 2012;71:1–7.
2. Nozaki R, Ishibashi K, Adachi N, Nishihara S, Adachi S. Accidental profound hypothermia. *N Engl J Med*. 1986;315(26):1680.
3. Gilbert M, Busund R, Skagseth A, Nilsen PA, Solbo JP. Resuscitation from accidental hypothermia of 13.7 degrees C with circulatory arrest. *Lancet* (London, England). 2000;355(9201):375–376.

others further include a profound category. Table 30-3 delineates the staging of hypothermia and associated physiologic changes.

Lastly, a clinical staging system is increasingly utilized based on the Swiss staging system, particularly when accurate measurements of core body temperature are not feasible. The staging system ranges from HT I to HT IV. In HT I, the individual is both conscious and shivering; in HT II, the individual has impaired consciousness and is no longer shivering; in HT III, the individual is unconscious, not shivering, but has vital signs; and in HT IV, the individual no longer has vital signs.

Clinical Features

Hypothermia is insidious in onset and early identification may be difficult. Accidental hypothermia must be suspected and recognized to administer appropriate therapy. Evaluating suspected hypothermia-related cases should include a clinical history, physical examination, and obtaining the rectal temperature.

Although hypothermia is defined as a core body temperature below 35°C (95°F), signs and symptoms may begin to appear at body temperatures of 36.0°C (96.8°F), including increased metabolic rate, elevated blood pressure, and increased muscle tension. Additional signs and symptoms are increasingly apparent as the core body temperature declines. Between 25°C (77°F) and 32.2°C (90°F), shivering diminishes and peripheral vasoconstriction is lost. Below 25°C (77°F), coordinated heat regulatory and heat conservation mechanisms are nonfunctional (see Table 30-3).[14]

Treatment

Hypothermia is a medical emergency, and rewarming is the goal of hypothermia management. In general, rewarming someone with suspected hypothermia should not be delayed either to find a low-reading thermometer or to run a clinical laboratory test. Rewarming can be active or passive and will depend on the available resources and current atmospheric environment. In passive rewarming (also called spontaneous rewarming), normal physiologic heat production is maximized through insulating the affected individual (including the head) and sheltering them from atmospheric conditions.[41] Since passive rewarming depends on an intact thermoregulatory system, it should only be employed as the sole source of rewarming with mild hypothermia cases, when core temperature exceeds 32.2°C (90°F).[42] In previously healthy and conscious individuals suffering mild hypothermia, voluntary physical activity and warm, nonalcoholic and decaffeinated beverages may be considered in addition to insulation. Moreover, if an individual with mild hypothermia is wearing wet clothing, it should only be removed after the individual has reached a warm, dry, sheltered environment because removing the clothing in the field can produce more rapid heat loss.[43] To maximize rewarming, distal extremities should be kept cool because warm hands and feet can reduce the stimulus for heat production and increase vascular dilation, thereby increasing heat loss.[43]

With core temperatures below 32.2°C (90°F), active rewarming is generally required. Active rewarming involves a source to conduct heat directly to the individual. This includes a variety of methods, ranging from noninvasive sources including heated garments, water immersion at 40°C (104°F), and heated and humidified air, to more invasive techniques involving heated dialysate (40°C [104°F]) in peritoneal dialysis and blood rewarming procedures (eg, cardiopulmonary bypass, arteriovenous rewarming, venovenous rewarming, hemodialysis).[44] Ideally, when core temperatures are significantly below 32.2°C (90°F), individuals should be transported to definitive medical care for careful

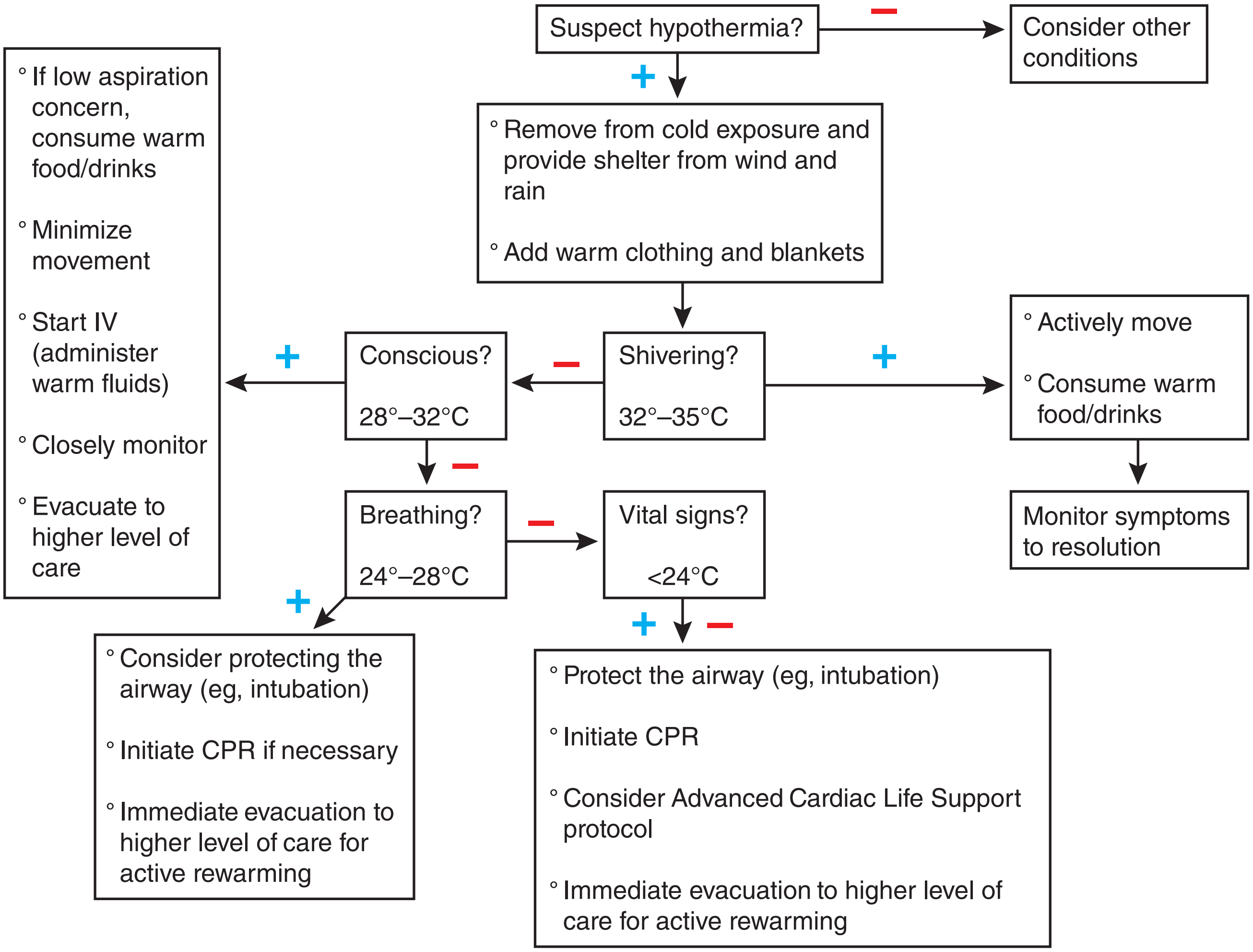

Figure 30-4. Initial treatment algorithm for hypothermia.
Data sources: (1) Brown DJ, Brugger H, Boyd J, Paal P. Accidental hypothermia. *N Engl J Med*. 2012;367(20):1930–1938. (2) Durrer B, Brugger H, Syme D. The medical on-site treatment of hypothermia: ICAR-MEDCOM recommendation. *High Alt Med Biol*. 2003;4(1):99–103.

monitoring and rewarming; core temperatures this low can cause cardiac arrhythmias, pulmonary edema, fluid imbalances, coagulopathies, acid-base imbalance, electrolyte disturbances, and blood glucose variations. Figure 30-4 displays a basic decision algorithm for initial hypothermia management.

MEDICAL SURVEILLANCE

Three vital components to identify before work begins in cold environments include (1) determination of the physical and mental qualifications appropriate to the specific job, (2) medical evaluation of the worker's physical and psychological ability to work in the cold, and (3) identification of specific medical conditions that may disqualify the individual from work in cold environments.[45] Even with appropriate protective equipment, cold stress can still place significant demands on the body, and inappropriately qualifying individuals to work in the cold can risk the safety of the individual as well as those he or she supports.

Medical history should be screened carefully to determine potential risk factors for suffering a cold-related injury. For instance, conditions that may preclude work in certain cold environments (below -1°C [30.2°F]) include exertional angina, previous cold injury, asthma, peripheral vascular disease, coronary artery disease, drug and alcohol abuse, and thermoregulatory disorders.[46] Other risk factors identified in the literature include gender and race (women and African Americans are at higher risk), poor physical conditioning, fatigue, and inadequate caloric intake.[5,31,38] Also, because cold exposure encompasses a wide range of atmospheric conditions, much colder conditions (below -24°C [-11.2°F]) with wind speeds less than 5 miles per hour, or air temperature below -18°C (0°F) with wind speeds above 5 miles per hour, should warrant medical clearance.

Since cold injuries are preventable, there should be a strong focus on appropriate prevention measures and early identification and treatment, especially during deployments in the field. Medical providers and supporting staff should communicate closely with commanders and supervisors to ensure proper recommendations are disseminated and practiced, particularly in the training environment.

PREVENTION

For all work required in cold environments, adequate protective barriers, insulated clothing, safe work cycles, and early identification of cold injuries will significantly decrease morbidity from the cold. As mentioned previously, protective shielding from the wind and rain will reduce additional heat loss. Furthermore, proper cold weather clothing can maximize body temperature homeostasis. The degree of insulation will depend on clothing factors such as fabric material, thickness, and amount of dead-space air trapped within a garment or between garments.[47] Clothing can be assigned a value known as a *clo* unit. This unit expresses the relative resistance to heat transfer by clothing. Specifically, a clo unit is the amount of thermal insulation that allows a person at rest (whose metabolic rate is 58 W/m^2) to maintain thermal equilibrium in an environment at 21°C (69.8°F) in a normally ventilated room (0.1 m/s air movement) with relative humidity less than 50%.[48] The approximate amount of clothing insulation needed at different air temperatures and physical activity levels measured by metabolic equivalents is depicted in Figure 30-5. Table 30-4 provides examples of various articles of clothing and associated insulator factor.

In extremely cold environments, where multiple layers of clothing are required, clothing layers should maximize the ability to wick moisture away from the body and limit cooling effects from wind and rain. For example, inner layers could consist of materials such as polypropylene, which help wick moisture to outer

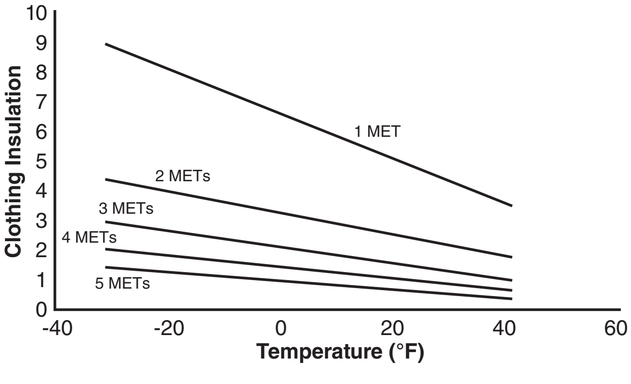

Figure 30-5. Approximate clothing insulation needed at different air temperatures and physical activity level. Wind speed is assumed to be less than 5 mph. At higher wind speeds, a windproof layer may be needed. One MET refers to energy expenditure at rest.
MET: metabolic equivalent
Adapted from: US Department of the Army. *Prevention and Management of Cold-Weather Injuries*. Washington, DC: DA; 2005: 22. Technical Bulletin MED 508.

TABLE 30-4.

INSULATION VALUE OF VARIOUS CLOTHING

Clothing Item	Insulation Value (Clo)*
Short sleeve shirt	0.18–0.25
Long sleeve shirt	0.22–0.29
Long sleeve sweater	0.20–0.37
Long underwear	0.20–0.30
Long pants	0.26–0.35
Socks (knee high)	0.08–0.13
Army improved physical fitness uniform	0.30
Army PT uniform with nylon pants and jacket	0.70
Battle dress uniform (BDU)	1.15
Expedition-weight polypropylene underwear	1.35
ECWCS (US Army) field coat and trouser liners	1.93
Gore-Tex[†] parka and trousers	1.95
Fleece jacket, bib overall	2.37
Total ECWCS (US Army)	3.4

*Ranges of clo values depend on clothing thickness and material.
[†]WL Gore & Associates, Newark, DE
ECWCS: Extended Cold Weather Clothing System
PT: physical training
Data sources: (1) US Department of the Army. *Prevention and Management of Cold-Weather Injuries*. Washington, DC: DA; 2005. Technical Bulletin MED 508. (2) Goldman R, Kampmann B. *Handbook on Clothing. Biomedical Effects of Military Clothing and Equipment Systems*. 2nd ed. Brussels, Belgium: NATO Research Study Group 7; 2007.

layers; intermediate layers of wool or Thinsulate (3M, St Paul, MN) provide added insulation; and outer layers should be wind-resistant and water-repellant (eg, Gore-Tex; WL Gore & Associates, Newark, DE), allowing moisture generated from perspiration to evaporate. Similar laying should occur with the hands, feet, and head. When wearing cold weather clothing, a helpful mnemonic ("COLD") can be used[9]:

- **C:** Keep clothing **C**lean
- **O:** Avoid **O**verheating
- **L:** Wear **L**oose and in **L**ayers
- **D:** Keep clothing **D**ry

Depending on the environment and work duties, insulation of exposed skin may not necessarily be needed; however, outdoor work with exposure to UV radiation should prompt use of sunscreen products as well. Additionally, proper eye protection can mitigate corneal abrasions and photokeratitis from a combination of wind, snow, ice, and UV radiation.

Table 30-5 provides recommended guidance on administrative controls and work cycles in cold environments, based on environmental conditions. However, when progressive signs and symptoms of cold injury become apparent, regardless of the environmental temperature, it is paramount to evaluate and appropriately treat the person prior to returning the individual to his or her duties. Prolonged cold exposure can inhibit the sensation of cold, which highlights the importance of supervision and having a buddy system.

Due to the increased metabolic demand of working in cold environments and the potential for cold diuresis, adequate nutrition and hydration should be stressed. Food is the fuel that helps generate and maintain the body core temperature, and a deficiency in critical fuel sources (carbohydrates, proteins, fats) may impact survival. Furthermore, dehydration can reduce appetite, further compounding cold environmental hazards. In general, and depending on activity level, military personnel need to increase their caloric consumption by 10% to 40% when operating in cold environments.[49] Specific rations have been developed with higher caloric content for cold weather operations such as the Meal, Cold Weather/Food Packet, Long Range Patrol (MCW/LRP) and the Ration, Cold Weather (RCW).

Leaders and supervisors should also establish a program for regular hydration. Actual fluid requirements depend upon the level of physical activity; however, urine that is dark yellow may signify inadequate fluid intake. Hot drinks may also be beneficial because the additional warmth can elevated mood.[50] Caution, however, should be taken to limit excessive

TABLE 30-5

WORK CYCLE RECOMMENDATIONS DURING COLD ENVIRONMENTAL CONDITIONS

Air Temperature with Sunny Sky		No Noticeable Wind		Wind 5 mph (8 km/h)		Wind 10 mph (16 km/h)		Wind 15 mph (24 km/h)		Wind 20 mph (32 km/h)	
°C	°F	Max Work Period	No. of Breaks	Max Work Period	No. of Breaks	Max Work Period	No. of Breaks	Max Work Period	No. of Breaks	Max Work Period	No. of Breaks
-26 to -28	-15 to -19	2 h	norm	2 h	norm	75 min	2	55 min	3	40 min	4
-29 to -31	-20 to -24	2 h	norm	75 min	2	55 min	3	40 min	4	30 min	5
-32 to -34	-25 to -29	75 min	2	55 min	3	40 min	4	30 min	5		
-35 to -37	-30 to -34	55 min	3	40 min	4	30 min	5				
-40 to -42	-40 to -44	30 min	5								
≤ -43	≤ -45					Emergency Work ONLY					

The work cycle schedule applies to a 4-hour period of moderate to heavy intensity work. Normal breaks are assumed to take place once every 2 hours.

Table courtesy of the Canadian Centre for Occupational Health and Safety—Occupational Health and Safety Division of the Government of Saskatchewan.

Other data sources: (1) American Conference of Governmental Industrial Hygienists. *2013 TLVs and BEIs—Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH: ACGIH; 2013: 2-2. (2) Occupational Safety and Health Administration. Cold stress. https://www.osha.gov/dts/weather/winter_weather/windchill.html. Accessed May 8, 2017.

caffeine consumption, which can lead to difficulty sleeping, and withdrawal can also cause headaches and nausea. Fluids such as alcohol are discouraged not only because they can impair judgment, but also because they can provide a false sense of feeling warm. Cold acclimatization programs should be considered if training allows; however, since their benefits are significantly less effective compared to heat acclimatization programs, the other preventive modalities should receive significantly more attention.

SUMMARY

The cold environment is unforgiving and has accounted for countless deaths in civilian and military operations. Although the weather and external environment cannot be altered, CWIs can be prevented with proper training and equipment. Early identification of CWIs should be addressed promptly before irreversible damage is done. With increased awareness among all military personnel, from senior supervisors to front line operators, cold weather casualties can be reduced significantly.

REFERENCES

1. Paton BC. Cold, casualties, and conquests: the effects of cold on warfare. Section II: Cold Environments. In: Pandolf KB, Burr RE, eds. *Medical Aspects of Harsh Environments.* Vol 1. In: *Textbooks of Military Medicine*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2001: 311–349.

2. Taylor MS. Cold weather injuries during peacetime military training. *Mil Med*. 1992;157(11):602–604.

3. Moran DS, Heled Y, Shani Y, Epstein Y. Hypothermia and local cold injuries in combat and non-combat situations—the Israeli experience. *Aviat Space Environ Med*. 2003;74(3):281–284.

4. Vaughn PB. Local cold injury—menace to military operations: a review. *Mil Med*. 1980;145(5):305.

5. DeGroot DW, Castellani JW, Williams JO, Amoroso PJ. Epidemiology of U.S. Army cold weather injuries, 1980–1999. *Aviat Space Environ Med*. 2003;74(5):564–570.

6. Eyolfson DA, Tikuisis P, Xu X, Weseen G, Giesbrecht GG. Measurement and prediction of peak shivering intensity in humans. *Eur J Appl Physiol*. 2001;84:100–106.

7. Hamlet MP. Human cold injuries. In: Pandolf K, Swaka M, Gonzales R, eds. *Human Performance Physiology and Environmental Medicine at Terrestrial Extremes*. Indianapolis: Benchmark Press; 1988: 435–466.

8. Sawka M, Young A. Physiological systems and their responses to conditions of heat and cold. In: Tipton C, ed. *ACSM's Advanced Exercise Physiology*. Baltimore, MD: Lippincott Williams and Wilkins; 2006: 535–563.

9. US Department of the Army. *Prevention and Management of Cold-Weather Injuries*. Washington, DC: DA; 2005. Technical Bulletin MED 508.

10. Gooden BA. Mechanism of the human diving response. *Integr Physiol Behav Sci*.1994;29(1):6–16.

11. Navy Environmental Health Center. *Prevention and Treatment of Heat and Cold Stress Injuries*. Portsmouth, VA: Bureau of Medicine and Surgery; 2007.

12. Bagley JR, Judelson DA, Spiering BA, et al. Validity of field expedient devices to assess core temperature during exercise in the cold. *Aviat Space Environ Med*. 2011;82(12):1098–1103.

13. Lefrant J-Y, Muller L, de La Coussaye JE, et al. Temperature measurement in intensive care patients: comparison of urinary bladder, oesophageal, rectal, axillary, and inguinal methods versus pulmonary artery core method. *Intensive Care Med*. 2003;29(3):414–418.

14. Auerbach PS. *Wilderness Medicine*. 6th ed. Philadelphia, PA: Elsevier Health Sciences; 2012.

15. Hall A, Evans K, Pribyl S. Cold injury in the United States military population: current trends and comparison with past conflicts. *J Surg Educ*. 2010;67(2):61–65.

16. Candler WH, Ivey H. Cold weather injuries among U.S. soldiers in Alaska: a five-year review. *Mil Med*. 1997;162(12):788–791.

17. Ingram BJ, Raymond TJ. Recognition and treatment of freezing and nonfreezing cold injuries. *Curr Sports Med Rep*. 2013;12(2):125–130.

18. Strohecker B, Parulski CJ. Frostbite injuries of the hand. *Plast Surg Nurs*. 1997;17(4):212–216.

19. Su CW, Lohman R, Gottlieb LJ. Frostbite of the upper extremity. *Hand Clin.* 2000;16(2):235–247.

20. Punja K, Graham M, Cartotto R. Continuous infusion of epidural morphine in frostbite. *J Burn Care Rehabil*. 1998;19(2):142–145.

21. Murphy JV, Banwell PE, Roberts AHN, McGrouther DA. Frostbite: pathogenesis and treatment. *J Trauma*. 2000;48(1):171–178.

22. Cauchy E, Cheguillaume B, Chetaille E. A controlled trial of a prostacyclin and rt-PA in the treatment of severe frostbite. *N Engl J Med*. 2011;364(2):189–190.

23. Foray J, Baisse PE, Mont JP, Cahen C. Treatment of frostbites. Analysis of results in twenty patients with buflomedil chlorhydrate (author's transl). *Sem Hop*. 1980;56(9–10):490–497.

24. Hayes DW Jr, Mandracchia VJ, Considine C, Webb GE. Pentoxifylline. Adjunctive therapy in the treatment of pedal frostbite. *Clin Podiatr Med Surg*. 2000;17(4):715–722.

25. Snider RL, Porter JM. Treatment of experimental frostbite with intra-arterial sympathetic blocking drugs. *Surgery*. 1975;77(4):557–561.

26. Weatherley-White RC, Sjostrom B, Paton BC. Experimental studies in cold injury. II. The pathogeneisis of frostbite. *J Surg Res*. 1964;4:17–22.

27. Imray CH, Richards P, Greeves J, Castellani JW. Nonfreezing cold-induced injuries. *J R Army Med Corps*. 2011;157:79–84.

28. Jurkovich GJ. Environmental cold-induced injury. *Surg Clin N Am*. 2007;87:247–267, viii.

29. Tlougan BE, Mancini AJ, Mandell JA, Cohen DE, Sanchez MR. Skin conditions in figure skaters, ice-hockey players and speed skaters: part II—cold-induced, infectious and inflammatory dermatoses. *Sports Med*. (Auckland, NZ) 2011;41:967–984.

30. Daanen HA, van der Struijs NR. Resistance Index of Frostbite as a predictor of cold injury in arctic operations. *Aviat Space Environ Med*. 2005;76(12):1119–1122.

31. Connor RR. Update: cold weather injuries, active and reserve components, U.S. Armed Forces, July 2009–June 2014. *MSMR*. 2014;21(10):14–19.

32. Ungley C. Peripheral vasoneuropathy after chilling "immersion foot and immersion hand." *Lancet*. 1942;240:447–451.

33. Ungley CC, Channell GD, Richards RL. The immersion foot syndrome. *Wilderness Environ Med*. 2003;14(2):135–141.

34. Webster D, Woolhouse F, Johnston J. Immersion foot. *J Bone Joint Surg Am*. 1942;24:785–794.

35. Mills W. Peripheral non-freezing cold injury: immersion injury. *Alaska Med*. 1993;35(1):117–128.

36. Cappaert TA, Stone JA, Castellani JW, Krause BA, Smith D, Stephens BA. National Athletic Trainers' Association position statement: environmental cold injuries. *J Athl Train*. 2008;43(6):640–658.

37. Brown DJ, Brugger H, Boyd J, Paal P. Accidental hypothermia. *N Engl J Med*. 2012;367(20):1930–1938.

38. Centers for Disease Control and Prevention. Hypothermia-related deaths—United States, 2003-2004. *MMWR*. 2005;54(7):173–175.

39. Centers for Disease Control and Prevention. Number of hypothermia-related deaths, by sex—national vital statistics system, United States, 1999-2011. *MMWR*. 2013;61:1050. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6151a6.htm. Accessed August 18, 2017.

40. Young AJ, Castellani JW, O'Brien C, et al. Exertional fatigue, sleep loss, and negative energy balance increase susceptibility to hypothermia. *J Appl Physiol*. 1998;85(4):1210–1217.

41. Handley A, Golden F, Keatings W, et al. *Report of the Working Party on Out of Hospital Management of Hypothermia*. London, England: Medical Commission on Accident Prevention; 1993.

42. Lazar HL. The treatment of hypothermia. *N Engl J Med*. 1997;337(21):1545–1547.

43. Kaufman W. The development and rectification of hikers hypothermia. In: Wittmers L, ed. *The Nature and Treatment of Hypothermia*. Minneapolis, MN: University Minnesota Press; 1983: 46–57.

44. Hayward JS, Steinman AM. Accidental hypothermia: an experimental study of inhalation rewarming. *Aviat Space Environ Med*. 1975;46(10):1236–1240.

45. International Organization for Standardization. *Ergonomics of the Thermal Environment—Medical Supervision of Individuals Exposed to Extreme Hot or Cold Environments*. Geneva, Switzerland: ISO; 2001.

46. Whayne T, DeBakey D. *Cold Injury, Ground Type*. Washington, DC. Office of the Surgeon General: Department of the Army; 1958.

47. Young AJ, Roberts DE, Scott DP, Cook JE, Mays MZ, Askew EW. *Sustaining Health and Performance in the Cold: A Pocket Guide to Environmental Medicine Aspects of Cold-Weather Operations*. Natick, MA: US Army Research Institute of Environmental Medicine; 1992. USARIEM Technical Note 93-2.

48. Yan YY, Oliver JE. The clo: A utilitarian unit to measure weather/climate comfort. *Int J Climatol*. 1996;16(9):1045–1056.

49. Thomas CD, Baker-Fulco CJ, Jones TE, King N, Jesior DA. *Nutritional Guidance for Military Operations in Temperate and Extreme Environments*. Natick, MA: US Army Research Institute of Environmental Medicine; 2001.

50. Scott D, Rycroft JA, Aspen J, Chapman C, Brown B. The effect of drinking tea at high altitude on hydration status and mood. *Eur J Appl Physiol*. 2004;91(4):493–498.