Frostbite

Pathophysiology, Epidemiology, Diagnosis, Treatment, and Prevention

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ABSTRACT

Frostbite can occur during cold-weather operations when the temperature is <0°C (<32°F). When skin temperature is ≤–4°C (≤25°F), ice crystals form in the blood, causing mechanical damage, inflammation, thrombosis, and cellular death. Lower temperatures, higher wind speeds, and moisture exacerbate the process. The frozen part or area should not be rewarmed unless the patient can remain in a warm environment; repeated freeze/thaw cycles cause further injury. Treatment involves rapid rewarming in a warm, circulating water bath 37°C to 39°C (99°F–102°F) or, if this is not possible, then contact with another human body. Thrombolytics show promise in the early treatment of frostbite. In the field, the depth and severity of the injury can be determined with laser Doppler ultrasound devices or thermography. In hospital settings, bone scintigraphy with single-photon emission computed tomography (SPECT) 2 to 4 days postinjury provides detailed information on the depth of the injury. Prevention is focused primarily on covering exposed skin with proper clothing and minimizing exposure to wind and moisture. The Generation III Extended Cold Weather Clothing System is an interchangeable 12-piece clothing ensemble designed for low temperatures and is compatible with other military systems. The Extreme Cold Vapor Barrier Boot has outer and inner layers composed of seamless rubber with wool insulation between, rated for low temperatures. The Generation 3 Modular Glove System consists of 11 different gloves and mitts with design features that assist in enhancing grip, aid in the use of mobile devices, and allow shooting firearms. Besides clothing, physical activity also increases body heat, reducing the risk of frostbite.

Keywords: *temperature; wind; moisture; thrombolytics; laser Doppler ultrasound; bone scintigraphy; computed tomography; Extended Cold Weather Clothing System; Extreme Cold Vapor Barrier Boot; Generation 3 Modular Glove System; physical activity*

Introduction

Historians have documented the adverse effects of cold weather on military operations since the beginning of recorded history. In 401/400 BCE, Xenophon marched 10,000 retreating Greek soldiers across the Armenian mountains, and only about 4,000 survived. Most were lost to exposure and frostbite. Hannibal crossed the Alps in October 218 BCE with plans to conquer Rome. He lost 28,000 of 47,000 men, largely because of the cold and mountain tribes who opposed him. During Napoleon's retreat from Moscow in 1812, temperatures fell to near –40°C (–40°F). The retreat started with about 110,000 soldiers, but by the time the Army arrived in Poland, only 10,000 effective soldiers remained. During the American Civil War (1861–1865), there were an estimated 15,000 injuries resulting from the cold. Amputations were common, many for frostbite. In the first few months of WWI, the British Army suffered 9,000 cases of what medical personnel recorded as "frostbite." On the WWI eastern front, Russians reported that 8% of all casualties were the result of cold, and the Germans reported 10,000 frostbite cases in a single night. In WWII, it was estimated that lost man-days resulting from cold injury was equivalent to 7,579 lost man-years, or an entire division (i.e., 10,000 to 15,000 Soldiers) out of action for 6 months. In 1944/1945, cold injury losses among riflemen were equivalent to the lost fighting strength of 12 divisions. During the Soviet invasion of Finland in early WWII, 7% of injured Russian troops and 12% of injured Finnish troops suffered frostbite. In the Korean War battle at Chosin Reservoir, US Marines fought Chinese Communist troops. Among the Marines were 2,700 nonbattle casualties, of which 2,000 (74%) were frostbite cases.[1–3] There are documented cases in which frostbite has hampered operations or resulted in mission failure among Special Forces soldiers.[4,5]

The cases of serious cold-related injuries have decreased in more recent years[6,7] largely because of a better understanding of physiologic responses to cold weather,[8] the development of

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improved clothing ensembles,[9,10] and leadership emphasis on cold-injury prevention.[11] Nonetheless, cold-weather injuries still occur, and there are reasons to assume that military operations in colder areas of the world might increase. Climate change has resulted in the melting of arctic ice.[12] There will likely be competition for natural resources in Arctic areas, including oil reserves that were previously inaccessible and where national boundaries are not clearly delineated. Sea lanes across the Arctic Ocean are opening, and their use can reduce ocean transit times and avoid Panama Canal and Suez Canal fees, but these areas are largely in Russian territory.[13,14] These facts increase the likelihood that US forces will be deployed to colder areas of the world for peacekeeping, handling of natural disasters, and other national security operations. It is expected that cold-weather training operations will increase and that the United States will partner with coalition allies in these efforts.[14] Medical personnel planning for cold-weather operations should emphasize cold-injury prevention and prepare for the treatment of cold-related injuries.

Among the most serious cold weather–related injuries is frostbite. Low temperature exacerbated by wind and surface moisture results in body cooling and the shunting of blood away from the extremities. If the blood flow to the extremities is restricted long enough and skin temperatures fall low enough, ice crystals will form in the blood, and tissues will freeze. Frostbite will occur, with the resulting tissue necrosis and the potential for catastrophic amputation in the affected parts.[15,16] This article covers the pathophysiology, epidemiology, diagnosis, treatment, and prevention of frostbite.

Pathophysiology

Frostbite is part of a spectrum of cold temperature–induced local injury that ranges from minimal chilling of the skin without impairment to major tissue damage from the development of extracellular ice crystals.[17] Frostnip is the least severe condition on this spectrum. Frostnip generally involves a drop in the local temperature of the epidermal and dermal skin layers, with some local pain and/or numbness but no injury to the skin tissues.[18] Chilblains (also called pernio) is a more serious condition associated with repeated exposure to near-freezing, dry environmental conditions. Individuals experience burning sensations, pruritus, swelling, and erythema. Blisters and ulcerations may occur in more severe cases.[18–20] Histologic studies indicate inflammatory infiltrates (mainly lymphocytes), necrotic keratinocytes, and microthrombi in the dermis.[19]

Frostbite is the most serious injury on this spectrum. It occurs when body tissues are exposed to temperatures below freezing and the tissues are damaged through direct and indirect mechanisms associated with freezing body fluids. Lower temperatures, wind, and moisture exacerbate this process.[21] Pathophysiologic changes are depicted in Figure 1 and involve two different mechanisms: (1) direct cellular damage and (2) effects from vascular inflammation, thrombosis, and ischemia.[15,22] When peripheral tissues (e.g., fingers, toes, ears, nose) are first exposed to cold temperatures, they respond with cycles of vasoconstriction and vasodilation. Cold-induced vasodilation (CIVD) warms the tissue by allowing blood from the warmer body core to enter the peripheral circulation, while vasoconstriction promotes cooling. When heat loss is great enough, the vasodilation/vasoconstriction cycles cease, and ice crystals begin to form in the extracellular fluids. This increases osmotic pressure and draws free water from cellular spaces, resulting in intracellular dehydration, hyperosmolality, decreased pH, and denaturing of lipids and proteins that damage cell membranes and result in cellular necrosis. Ice crystals also mechanically damage cell membranes and slow blood flow. These factors initiate an inflammatory response and release of the inflammatory mediators (prostaglandins, thromboxane, bradykinin, histamine) that cause platelet and leukocyte aggregation and thrombosis in affected tissue, leading to ischemia and cell death.[17,21–23]

Once exposed to a warmer environment, vasodilation resumes, resulting in reperfusion injury and a further increase in the inflammatory response. The thin layer of endothelial cells separates from blood vessels. Capillary leakage from damaged endothelial cells can form epidermal blisters. An increase in the

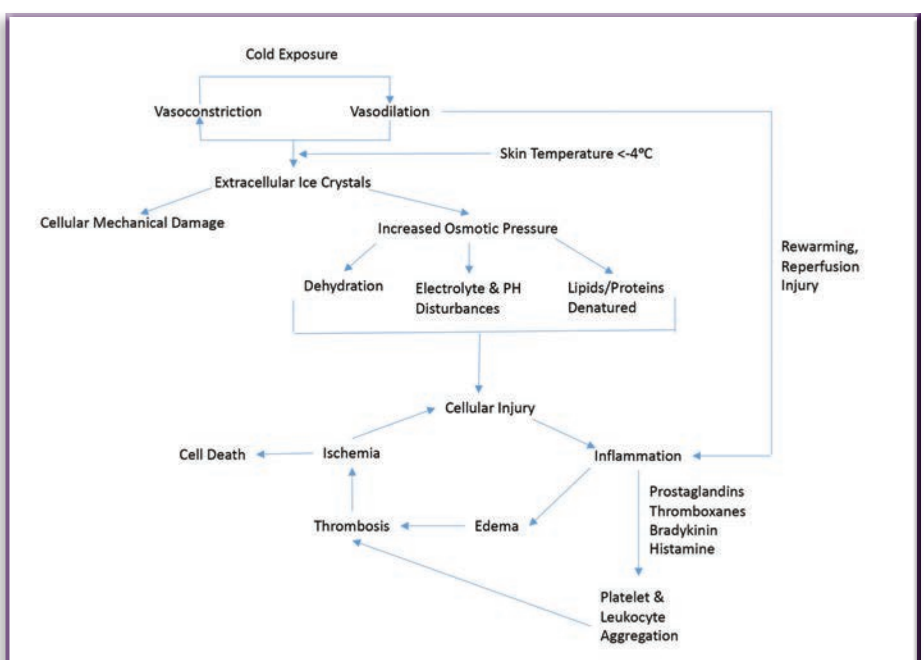


FIGURE 1 *Pathophysiology of frostbite.*

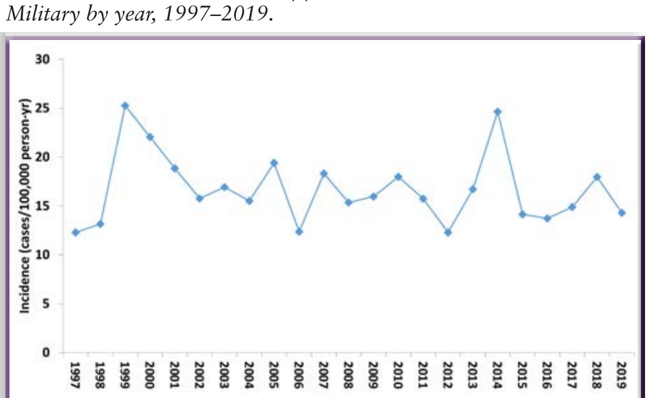
enzymatic activity of blood coagulation factors also occurs, further increasing the thrombosis.[24] With rewarming comes a partial thawing of tissue and edema from melting ice. Depending on the depth of the freezing, skin, nerve, fat, muscle, and bone tissue can be involved. Nerve, cartilage, bone, and endothelial cells are injured more rapidly than skin, fat, or connective tissue.[17] Epiphyseal cartilage (involved in the growth of long bones) is particularly susceptible to freeze damage. Loss of mitochondria can occur in muscle cells.[22,23]

Epidemiology

Incidence of Frostbite in the Military

Every year since 1995, the Armed Forces Health Surveillance Branch of the Defense Health Agency has reported on the incidence of cold injuries, including frostbite. These reports are available in the Medical Surveillance Monthly Report at their website (https://www.health.mil/Military-Health-Topics/Combat-Support/Armed-Forces-Health-Surveillance-Branch/Reports-and-Publications/Medical-Surveillance-Monthly-Report). However, these reports generally cover only limited periods and do not present the incidence of frostbite over longer periods. To determine the frostbite incidence over the longest possible period, incidence rates for clinically diagnosed frostbite in the military population were obtained from the Defense Medical Epidemiology Database (DMED).[25] From 1997 to 2015, frostbite was indicated in the DMED with the *International Classification of Diseases,* Version 9 (ICD-9) code 999.0 (frostbite of face), 999.1 (frostbite of the hand), 999.2 (frostbite of the foot), and 991.3 (frostbite of other and unspecified sites). Beginning in 2016, the DMED switched to the *International Classification of Diseases*, Version 10 (ICD-10) codes. In the ICD-10, frostbite codes include a greater number of more specific anatomic locations (e.g., head, nose, neck, wrist). These codes are included in the ICD-10 series T33 (superficial frostbite, 37 codes) and T34 (frostbite with tissue necrosis, 37 codes) series. For the analysis reported here, the primary diagnosis and initial occurrence were selected for ICD-9 codes; the primary diagnosis, initial occurrence, and initial encounter (i.e., 7th character A code) were selected for ICD-10 codes. Both inpatient and outpatient cases were included. Incidence rates for each year were calculated as [new cases (n)/military population (n)] × 100,000. Thus, the incidence rate was expressed as cases/100,000 person-years. Figure 2 shows that the overall incidence of clinically diagnosed frostbite has remained relatively constant from 1997 to 2019 at about 17.5 cases/100,000 Service Members, but with peaks in 1999 and 2014 (both 25 cases/100,000).

FIGURE 2 *Overall incidence of frostbite in the United States Military by year, 1997–2019.*



In interpreting Figure 2, several facts should be considered, including who is exposed to cold weather and the likelihood of underreporting. In Figure 2, the denominator for the incidence calculation is the entire population of the military, not just those exposed to cold weather. In studies at Fort Wainwright, Alaska, during three winters (1967–1970), investigators reported a frostbite incidence of 1,550 cases/100,000 Soldiers,[26] considerably higher than that in Figure 2. In addition, the frostbite cases in Figure 2 are those clinically diagnosed—that is, cases in which the Servicemember reported to a medical care provider, and the provider diagnosed the injury as frostbite. The actual number of frostbite cases is likely underreported. For example, in an 11-day exercise in the high arctic where average temperatures averaged –21°C (–6°F) and wind chills –44°C (–47°F), 17% of Soldiers reporting to the unit medical station were diagnosed with frostbite. However, when medical personnel actively examined Soldiers at the conclusion of the exercise, investigators found that an additional 21% of the Soldiers experienced frostbite. The underreporting was attributed to Soldiers' not considering the injury sufficiently serious, engaging in self-treatment, or ignoring the injury to accomplish the mission.[27]

Table 1 shows the anatomic locations of frostbite injuries in the active duty US military from 2015 to 2019, where more diverse and specific anatomic locations were available using ICD-10 codes. About 41% of frostbite cases occurred in the foot/toe region and 38% in the hand/finger region, with all other or unspecified regions accounting for 21%. As shown in Table 2, other studies have also found that frostbite is most likely in the foot/toe and hand/finger regions.[28–35] However, under some circumstances, the head/face region may have a higher incidence.[26,31,36–39] During outdoor winter activity, the face is usually the most exposed region and under conditions of high wind and low temperature may suffer a high frostbite incidence. For example, reindeer herders often ride in snowmobiles and are exposed to high winds on their faces, and so experience a high frostbite incidence in this area.[36] Similarly, mountaineers often have exposed faces and may experience very high winds and very low temperatures at altitude, increasing risk of frostbite on the face.[39]

Risk Factors for Frostbite

The DMED provides data that are useful for examining some demographic factors that might be associated with frostbite in military personnel. To examine these, DMED data on the incidence of frostbite (ICD-9 codes 991.0, 991.1, 991.2, 991.3)

TABLE 1 *Anatomic Distribution of Frostbite Injuries, Active Duty US Military, 2016–2019**

Anatomic location	N	%
Face/head	55	7.2
Neck	4	0.5
Thorax/abdomen/low back/pelvis	7	0.9
Arm/wrist	15	2.0
Hand	101	13.3
Fingers	186	24.6
Hip/thigh/knee/ankle	31	4.1
Foot	131	17.3
Toe	176	23.2
Other/unspecified sites	51	6.7

*Data obtained from the Defense Medical Epidemiology Database.

TABLE 2 *Anatomic Distribution of Frostbite Injuries in Various Studies*

		Frostbite				
Study	Sample	Cases (n)	Feet/Toes (%)	Hands/Finger (%)	Head/Face (%)	Other
Vester and Ekman[28] (1953)	SMs treated in 48th Surgical Hospital (8th Army) in Korea, Winter 1950–1951	281	62	29	9	0
Sumner et al[26] (1974)	US Soldiers at Fort Wainwright, AK 1967–1970	292	28	25	41	7
Rosen et al[29] (1991)	Norwegian Soldiers, 1986–1989	40	57	37	6	0
Ervasti et al[36] (1991)	Reindeer herders in Finland (1-year incidence)	453	6	17	73	4
Valnicek et al[30]* (1993)	Hospital admissions in central Canada, 1969–1979	125	48	41	4	7
Lehmuskallio et al[31] (1995)	Finnish Conscripts, 1976–1989	2,054	NR	NR	45	NR
Hashmi et al[32] (1998)	Himalayan mountaineers treated in Pakistan hospitals, 1985–1994	1,500	64	32	3	1
Cattermole[37] (1998)	British Antarctic Survey Personnel, 1986–1995	61	27	21	47	3
Juopperi et al[33] (2002)	Hospital admissions in Finland, 1986–1995	1,212	61	34	5	0
Ervasti et al[38] (2004)	Finnish conscripts (lifetime occurrence)	2,555	22	32	46	0
Harirchi et al[39] (2005)	Mountaineers in Tehran, Iran (frostbite in last 2 years)	469	24	18	49*	0
Gallea et al[34] (2014)	Competitors in Iditarod Sled Dog Race, AK, 2010	20	45	35	20	0
Heil et al[35] (2016)	British Army, 2002–2015	149	45	53	2	0
DMED data	Clinically diagnosed cases, US Army, 2015–2019	757	41	38	8	13

*Estimated from data in article.
AK = Alaska, DMED = Defense Medical Epidemiology Database, NR = not reported, SM = Service Member, US = United States.

were compiled by sex, age, race, and military service for the years 1997 to 2015. Incidence rates were calculated using the entire population for each group (e.g., for women, incidence rate = new female cases (n)/female population (n) × 100,000 per year). Figure 3 shows the overall incidence by sex, age, race, service branch, and rank. Incidence was about 1.7 times higher for women compared with men (Figure 3A). Incidence declined with age (Figure 3B). Blacks had an incidence rate about 2.7 times higher than those of white or other ethnicities (Figure 3C). The Army had the highest incidence rate and the Navy the lowest, with the Army rate more than 7 times higher than that of the Navy (Figure 3D). Incidence was highest in the lower ranks and decreased as rank increased (Figure 3E).

A number of other studies have examined other risk factors for frostbite in military and civilian samples. Many studies[6,40,41] look at risk factors for any cold injury, but only studies that have specifically addressed frostbite are included here. Observational studies were considered only when they included both frostbite cases and non-cases (i.e., had a control group). Many studies[30,42,43] examine factors among frostbite victims only, and these are not appropriate because it is not known whether the incidence among cases might be similar to that of non-cases for a particular factor.

Comparisons can be made from the literature regarding the military frostbite risk factors mentioned above and in Figure 3. Male sex has been associated with more frostbite risk in civilian samples,[33,44] and why this differs from the military (Figure 3A) is not clear. Data on age are not consistent; one population-based study in Finland showed risk increasing with age,[33] while another showed risk of mild frostbite generally decreasing with age.[44] The higher risk among Blacks has been duplicated in a number of military investigations.[26,45–47] During experimental cold exposure, Blacks (compared with whites) have a more protracted peripheral vasoconstriction, fewer vasoconstriction/vasodilation cycles, less rapid rewarming, and

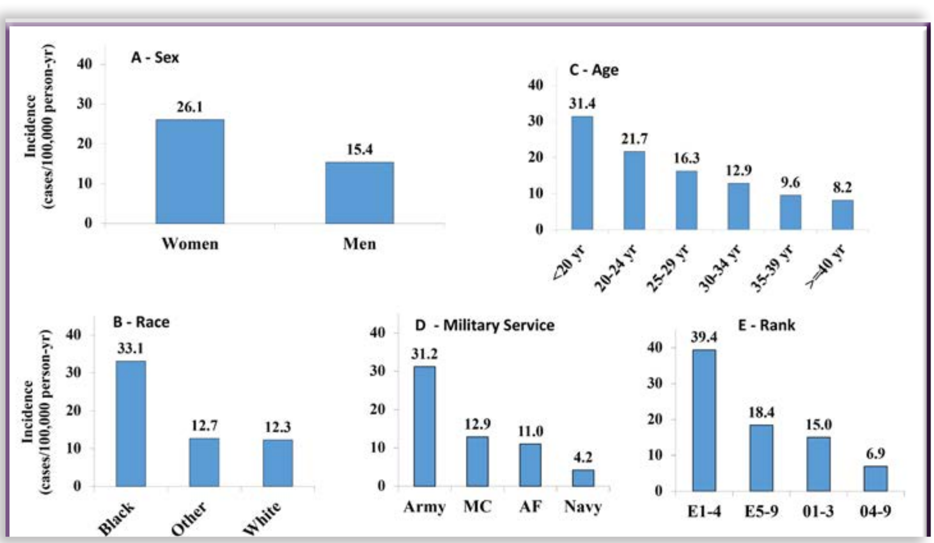


FIGURE 3 *Incidence of frostbite in the United States Military (1997–2015) by sex* (**A**), *age* (**B**), *ethnicity* (**C**), *service* (**D**), *and rank* (**E**).

AF = Air Force, E = enlisted ranks, MC = Marine Corps, O = officer ranks.

lower average and minimal skin blood flow.[48,49] These are all factors that could increase susceptibility to frostbite. Other studies have found that risk of frostbite decreases as rank increases,[26,46] possibly related to greater exposure, duties, or educational level among lower ranking personnel.[26]

Other studies have identified additional risk factors for frostbite. Environmental factors that increase the risk include low temperature and high wind,[33,37,50,51] longer exposure to cold,[26,44] and higher altitudes, especially >17,000 feet.[32] Travel in open vehicles increased risk,[31,36] likely because of exacerbated wind speed. Military recruits lacking proper clothing[31] had an increased risk of frostbite: lack of use of ear flaps increased risk for frostbite of the ears, and lack of use of a scarf increased risk for frostbite of the ears and face. Personal (i.e., intrinsic) factors that increased risk of frostbite include birthplace in warmer regions,[26] lower educational level,[26] type O blood (compared with A or B),[26] excessive sweating,[31] prior frostbite or frostnip injury,[37,52] and certain comorbidities (e.g., cardiac insufficiency, angina pectoris, diabetes, depression).[44] Cigarette smoking has been shown to increase risk in some studies[26,38] but not all.[36,46] It has been hypothesized[38] that acute vasoconstriction observed with smoking,[53] in concert with increased fibrinogen concentration, increased platelet activity, and other factors,[54] may exacerbate the thrombosis associated with frostbite. Other risk factors include heavy physical work,[44] vibration exposure,[38] use of topical ointments,[31,55,56] and lack of proper equipment while mountineering.[39]

Diagnosis

As shown in Table 1, 78% of frostbite cases in the US military have occurred in hands, fingers, feet, and toes, although 15% occur in other specified locations (7% are recorded in unspecified sites). In an initial clinical presentation, the patient with frostbite presents with either frozen or thawed skin, although in the field, the presentation is usually frozen skin. With skin in the frozen state, patients describe numbness and sensory loss in the affected area or areas and may complain of clumsiness and lack of control. The affected area is usually cold, firm to the touch, and white, but could be mottled blue, yellow-white, and/or have a waxy appearance. As the tissue warms and thaws, it will appear red because of hyperemia, and the numbness will be replaced by a throbbing sensation that can last for days or weeks. Edema and blistering (if present) occur during rewarming. Blisters that are clear, yellow, or pink and extend to the digits are favorable prognostic signs, while small, dark, or hemorrhagic blisters generally indicate a less favorable prognosis.[17,21,23]

Treatment

Field Care

Recommendations for field management of frostbite are based largely on clinical and practical experience. Because of the possibility of further injury and the loss of sensation in affected parts, individuals with frostbite should not use the frostbitten parts unless absolutely necessary. If only the toes are involved, it may be reasonable to walk for short distances; however, it is not judicious to do so if the entire foot is involved. Nonetheless, there are anecdotal reports of individuals who have walked for days on frozen feet.[2] If locomotion is not required or if frostbite involves only the hands, the affected parts should be wrapped in clothing, blankets, or other cloth material to avoid trauma from mechanical damage. Clean, dry gauze or sterile cotton dressings can be placed between the fingers and/or toes. Jewelry and other constrictive material should be removed. The patient should be moved carefully from windy conditions by seeking shelter.

Because repeated freezing and thawing can cause further damage (Figure 1), the injured part should not be rewarmed unless the patient can remain in a warm area. Rubbing the affected part should be avoided because it can cause further injury. If the patient is capable, warm oral fluids can be provided to maintain or improve hydration; if the patient is not capable of orally consuming fluids, then normal intravenous saline (preferably warmed to 37°C to 42°C [99°F–108°F]) can be provided, with consideration given to the fact that saline will cool over time in colder environments.[16,21,57] Ibuprofen is generally recommended because it reduces production of prostaglandins and thromboxanes that are associated with thrombosis and ischemia (Figure 1).[58] In the field, ibuprofen provided 12 mg/kg twice daily is recommended up to a maximum of 2400 mg/d total.[57]

Rewarming can be accomplished slowly or rapidly, although the latter is preferred, based on clinical experience.[23,57,59] In slow rewarming, the patient is moved to a warm area and passively allowed to rewarm. The affected body part can also be rewarmed by another individual using their body heat (e.g., placing the patient's hand in the axilla or groin of a buddy). Rapid rewarming of the affected part in a water bath is much more effective and is strongly recommended if available. The water bath should be heated to 37°C to 39°C (99°F–102°F) and a thermometer used to ensure accuracy of water temperature. In the absence of a thermometer, a care provider can check the water by placing a hand in it to assure it is tolerable. The water should be circulated and the temperature checked frequently because it will cool once the affected limb is placed in it. The frozen part can be considered adequately rewarmed when it assumes a red or purple color and is soft and pliable to the touch. The length of time necessary for rewarming depends on the extent of the injury but is usually 15 to 60 minutes. Rewarming with excessive heat (i.e., near campfires, stoves, or hot vehicle engines) should be avoided because of the possibility of thermal burns. Blisters should not be débrided in the field. Once the affected part is removed from the water bath, edema should be expected. Loose but bulky, dry sterile gauze should be placed around the affected part for protection and wound care.[23,57,59]

Classification

Classification of frostbite is undertaken after rewarming because on initial presentation, most frozen skin appears similar, regardless of the depth of tissue injury.[18,60] Examination should take into consideration skin color, skin temperature, sensation, and pulse. As shown in Table 3, two classification systems have been proposed to help determine the depth of the injury and prognosis. The traditional system has four levels or degrees, whereas the more modern system has two levels. In the traditional system, first-degree frostbite involves only superficial skin freezing that is essentially frostnip. There is no cyanosis, and on rewarming, the patient will report transient tingling and burning. Erythema will be evident, and edema will occur after 2 to 3 hours. There may be some epidermal skin loss. Second-degree frostbite involves freezing of both the epidermal and dermal skin layers. Cyanosis will be evident on the frozen parts and, on rewarming, the patient will report

TABLE 3 *Frostbite Classification Systems Based on Severity*

Modern Classification	Traditional Classification	Signs and Symptoms
Superficial (freezing limited to skin)	1st degree (superficial skin freezing)	• Absence of initial lesion • Erythema • Edema (2–3 hours; may continue for 1 month) • Minimal or absent initial lesions • Blisters occasionally seen, but not often • Occasional desquamation of skin (5–10 days later), but no deep tissue loss • Patient notes early transient tingling or burning, but generally intact sensation
	2nd degree (full-thickness skin freezing [epidermis and dermis])	• Erythema • Edema is likely, but disappears within a few days • Initial lesion on distal phalanges • Blisters with clear fluid (favorable prognosis) or hemorrhagic (unfavorable) • Hyperhidrosis (second or third week) • Desquamation of skin • Patient notes throbbing & aching pain lasting 3 to 10 days after injury
Deep (freezing involving skin and tissues below the skin)	3rd degree (full-thickness skin and subcutaneous tissue freezing)	• Generalized edema • Initial lesion on intermediary and proximal phalanges • Purple or hemorrhagic blisters • Some skin necrosis with hard, dry tissue (eschar) • Sloughing of skin with ulcerations • Patient notes no initial sensations, but later burning, aching, throbbing or shooting pains
	4th degree (full tissue freezing including muscle, tendon and bone)	• Little edema • Initial lesion on carpal or tarsal • Hemorrhagic blisters (when blisters present) • Initially area is cyanotic, mottled, or deep red; later area is dry and black • Extensive tissue necrosis & irreversible tissue damage • Patient notes initial insensitivity in area and severe pain on rewarming

throbbing and aching pain that can last 3 to 10 days postinjury. Erythema and blisters with clear or hemorrhagic fluid will be evident. Hyperhidrosis occurs in the second or third week. There will be loss of skin tissue. Third-degree frostbite involves damage to the full thickness of the skin in addition to subcutaneous tissues. The patient will report burning, aching, throbbing, or shooting pains beginning about day 5 and lasting 4 to 5 weeks. Blisters are smaller and can be hemorrhagic. There is a generalized edema that diminishes by day 5 or 6. There is skin necrosis and sloughing of skin. In fourth-degree frostbite, there is widespread destruction of tissue, including the bone. The patient initially will report insensitivity in the affected area, but there is severe pain on rewarming. There is little edema and, if blisters are present, they are hemorrhagic. Initially, the area is cyanotic, mottled, or deep red and later, dry and black. There is extensive tissue necrosis and irreversible tissue damage.[17,21,23] Varying degrees of frostbite can exist in different parts of the body.

The modern system better corresponds with the final prognosis.[23,61] It simply classifies frostbite as either superficial and deep and is considered more appropriate for field classification after spontaneous or formal rewarming.[57] Superficial frostbite is limited to the skin (no deeper tissues), has a good prognosis for recovery, and encompasses the signs and symptoms of traditional first- and second-degree frostbite. Deep frostbite involves the deeper tissues, is associated with tissue loss and disability, and encompasses the signs and symptoms of traditional third- and fourth-degree frostbite.[17,23]

Two additional systems have been developed to describe the extent of injury after rewarming. The Cauchy scale (Table 4) uses the amount of anatomic involvement to indicate the probability of amputation. The scale is based on clinical experience with 494 affected fingers and toes in 70 severely frostbitten patients.[61] The scale does not predict where the amputation should occur, which must be determined with imaging techniques described below. The much more involved Hennepin score[62] allows calculation of the extent of frostbite in the extremities and can be used to indicate the effectiveness of treatment outcomes. It is to be used after triple-phase bone scans (described below), which indicate the level of tissue perfusion. To calculate an at-risk score, the system assigns 50 points to each limb, then subdivides this value for various limb segments. For example, 15 points are assigned to a hand (the additional 35 points are assigned to the rest of the arm), with a single digit receiving 2 points. Of the two points, 0.5 point is assigned to distal phalange involvement, 0.5 point to the middle phalange, and 1 point to the proximal phalange. If the phalanges of all five digits on a single hand are involved. the patient is assigned a score of 10 points. Metacarpals and carpal involvement on a single hand are assigned an additional 5 points. The score describes the extent of tissue at risk, with

TABLE 4 *Cauchy System for Classifying the Extent of Frostbite Amputation Risk of Hands and Feet.*[61]

Grade	Extent of Involvement	Probability of Amputation (%)
1	Distal phalanx	0–1
2	Intermediary phalanx	23–39
3	Proximal phalanx	60–83
4	Metacarpal or metatarsal	98–100
5	Carpal or tarsal	100

more points indicating greater body involvement. To determine outcomes after management, an amputation score is calculated using the same point system described above for segments that are amputated after treatment. The salvage rate quantifies the effectiveness of the treatment and is calculated as (at-risk score – amputated score)/at-risk score =100%. Using this system, ratings among three independent scorers was very high (i.e., intraclass correlation = 0.93).[62]

Thrombolytic Therapy

Thrombolytics are drugs that break up thrombi and emboli in the vasculature and microvasculature. The use of thrombolytics in treating frostbite was first reported in 1992 at Hennepin County Hospital, Minnesota. The report provided preliminary results of a pilot study using recombinant tissue plasminogen activator (tr-PA) in frostbite treatment.[63] Since that time, there has been one randomized controlled trial[64] and several observational studies, case studies, and case series examining the effectiveness of this therapy. In the randomized controlled study,[64] 47 individuals with second- to fourth-degree frostbite were either administered intravenous iloprost (0.5–2 ng/kg body weight, 6 h/day) for 8 days plus tr-PA on the first day only (n = 32), or did not receive this treatment (n = 15). Patients administered iloprost had 2% of digits amputated compared with 40% in the group not receiving iloprost (relative risk [no iloprost / iloprost] = 24.75, 95% CI = 9.69–58.69).

Two systematic reviews[65,66] examined the effectiveness of thrombolytics for the treatment of frostbite. One review[65] examined 15 studies that included 208 patients treated with tr-PA and 94 untreated patients, all with frostbite of the extremities. The reviewers concluded that because of differences in treatment protocols, inclusion criteria, outcome measures, and methodologic quality, the efficacy of tr-PA for reducing amputation rates could not be established. They recommended more randomized prospective trials, even though virtually all investigations reported that tr-PA was or may have been useful in reducing amputation rates.

The second review[66] included 18 studies using any type of thrombolytics, including tr-PA, alteplase, urokinase, streptokinase, or any other tr-PA derivative. In this review, 216 of 325 patients were treated with thrombolytics. Combining all studies, the weighted average salvage rate for patients treated with thrombolytic infusion was 79%. This suggested that thrombolytics were a promising standard treatment for severe frostbite. Similar limb salvage rates were achieved with intravenous or intra-arterial administration. Complication rates were 3% for intravenous and 4% for intra-arterial administration. Factors associated with failed salvage after thrombolytic therapy included presentation >24 h, multiple freeze-thaw cycles, and >24 h of warm ischemia.

Cauchy et al[67] proposed that rt-PA administration be included in the management of severe frostbite in austere environments when there is little doubt of amputation if the injury is untreated (i.e., fourth-degree frostbite) and trained medical personnel are available for treatment. The suggested administration protocol is shown in Table 5. The Wilderness Medical Society Guidelines for the Prevention and Treatment of Frostbite recommends that "for deep frostbite injury with potential significant morbidity, angiography and use of either [intravenous] or intra-arterial rt-PA within 25h of thawing may salvage some or all of tissue at risk."[57]

TABLE 5 *Protocol for Administration of Intravenous Recombinant Tissue Plasminogen Activator by Training Medical Personnel for Individuals With Severe Frostbite in Austere Environments*[67]

Areas of Concern	Protocol and Considerations
Administration*	• Weight <67 kg: 15 mg IV bolus, then 0.75mg/kg over 30 min, then 0.35mg/kg over next 60 min.
	• Weight >67kg: 15 mg IV bolus, then 50mg over 30 min, then 35mg over next 60 min. Total not to exceed 100mg.
Contraindications	• Recent trauma, bleeding diathesis, stroke within 3 months, on anticoagulants, hypersensitivity; blood pressure >180mmHg systolic or 110mmHg diastolic.
Precautions	• High altitude: high altitude pulmonary or cerebral edema, retinal hemorrhage, gastritis.
Complications and management	• Bleeding: stop infusion, hemostasis if possible (consider tranexamic acid)
	• Angioedema: stop infusion, antihistamine, corticosteroids.

*Ideally given with a portable syringe pump.
IV = intravenous

Imaging

Various imaging techniques can assist in defining the severity, depth, and range of frostbite tissue injury and determining the viability of soft tissue and bone. Plain radiographs are often the first imaging technique used and can be useful in identifying soft-tissue swelling and tissue loss, especially at the distal phalanges. Osteopenia and periostitis may be observed weeks to months after the initial injury.[22,68]

Laser Doppler ultrasound devices are often available in the field and can assist in making the initial frostbite diagnosis, including severity.[69–71] This technique uses a laser beam that reflects off circulating red blood cells and uses the Doppler effect to image the movement of blood through tissues. When blood is moving away from the transducer head, the return signal has a lower Doppler-shifted frequency; when the blood is moving toward the transducer, the signal has a higher Doppler-shifted frequency.[72] Some commercial devices also provide measures of hemoglobin oxygenation and relative amount of hemoglobin, which may also be useful. One study[71] using a swine model showed that 3 hours after frostbite injury, there was a graded response dependent on the severity of the injury: in superficial frostbite injury, there was an increase in Doppler-detected blood flow and no change in hemoglobin oxygenation; in deep partial frostbite, there was a decrease in Doppler-detected blood flow and no change in hemoglobin oxygenation; and in deep frostbite (i.e., full-thickness injury), there was a decrease in Doppler-detected blood flow and in hemoglobin oxygenation.

Thermography is another noninvasive technique that detects and images heat radiating from the skin in the infrared portion of the electromagnetic spectrum (i.e., wavelengths of approximately 8 to 15µm). Variations in skin temperature are affected by variations in blood flow.[73] The images (called thermograms) are displayed in various colors, with a color reference scale showing the temperature of the skin surface. Human research of thermography in frostbite injury is limited, although studies have been conducted on animal models.[74–78] The most recent study[78] using a rat paw model showed that in superficial frostbite, skin temperature determined by thermography returned to normal 1 hour postexposure. In deep frostbite, skin temperature determined by thermography was near ambient temperature at 1 hour postexposure and for at least 1 week postexposure (i.e., end of study).[78] Further research on humans is needed, but thermography may be a promising technique to determine the severity of frostbite injury.

Other imaging techniques are more appropriate in hospital environments. Digital subtraction angiography (DSA) is a fluoroscopic technique that uses radiography to obtain real-time moving images of the blood vessels while masking out other structures (e.g., bone). It requires injection of a contrast dye. It is useful for patients presenting within 24 hours of a deep frostbite injury with suspected blood vessel involvement because it assesses blood vessel patency.[68,79] It has been suggested[68] that DSA might also be used to identify targets for thrombolytic agents and to determine the progress and effectiveness of this treatment.

Magnetic resonance imaging angiography is a noninvasive alternative to DSA that is also useful for examining blood vessel patency and assisting in determining the level of tissue loss. It allows precise visualization of blood vessels and provides a demarcation line between viable and nonviable tissue that can assist in surgical planning.[80,81] Some clinicians state that the utility of this technique has limitations.[68]

Bone scintigraphy involves injection of a low-level radioactive tracer into the frostbite-injured part and then use of a camera to image the gamma radiation released. The tracer is a phosphate labeled with technetium-99m (^{99m}Tc). This is used because of its rapid distribution, rapid clearance from blood and soft tissue, high uptake into the skeleton, and accumulation in proportion to the bone blood flow. This allows identification of anatomic locations that are more metabolically active.[82] Multiphase bone scintigraphy using ^{99m}Tc diphosphonates has been advocated for patients presenting with second- to fourth-degree frostbite. It should be performed 2 to 4 days postinjury.[68,83] The times at which the images are obtained provides different types of information. Images obtained 1 to 60 seconds postinjection provide information on microvascular blood flow; images obtained 3 to 10 minutes postinjection provide information on the soft tissue and microvasculature; delayed images obtained 2 to 4 hours postinjection provide information on bone perfusion because the tracer binds to calcium salts. Table 6 shows the physiologic significance of multiphase indicators in these tracer phases.[68,84] A second bone scan 7 to 8 days postinjury has been suggested in category 3 (Table 5) because some lesions may continue to degrade, while others may improve. Areas that do not take up the tracer in delayed images will likely require amputation (specificity = 0.99, sensitivity = 0.92).[83,84]

The addition of SPECT to multiphase ^{99m}Tc bone scintigraphy can improve diagnosis by identifying the precise anatomic level of bone necrosis. SPECT images are obtained immediately after acquiring bone scan delayed-phase images. The three-dimensional CT scans are viewed either side-by-side with the bone scans or combined by some commercial imagers. This provides precise anatomic identification of the demarcation line between viable and nonviable bone, allowing for more accurate surgical planning.[68,79,85]

Long-Term Sequelae

The most common long-term sequela from frostbite is a general hypersensitivity to cold in the affected area or areas.[86–89] Other persistent symptoms among frostbitten patients include hyperhidrosis, decreased tactile sensitivity, and pain.[86–89] Compared with unaffected areas, formerly frostbitten areas reach a lower skin temperature on exposure to cold.[88] In frostbitten toes and fingers, CIVD is delayed or abolished 3 to 4 years after the injury, suggesting higher susceptibility to future cold injury.[90] Among 40 soldiers followed up 6 months after a frostbite injury, 26 (65%) had symptoms consistent with neurovascular injury, including cold sensitivity paresthesia, pain, and hyperesthesia, as well as lower tolerance for cold water exposure.[89] Ninety-seven soldiers who suffered frostbite during the Korean War were contacted 4 years postinjury; as the severity of their reported frostbite increased (from second to fourth degree), so did the proportion reporting they were handicapped in obtaining employment or carrying out their current job.[87]

Prevention

It is important to understand the physiologic effects of temperature, wind, and moisture on skin and how to apply this information in the prevention of frostbite. Frostbite cannot occur when the air temperature is >0°C (>32°F). As air temperature decreases, exposed skin temperature decreases in a relatively linear manner. On the other hand, the effect of wind on skin temperature is curvilinear. That is, at lower wind speeds there is a rapid decrease in skin temperature; a near plateau in skin temperature is reached at about 9m/sec (20 miles/h); there are only modest changes in skin temperatures after this.[91,92] As skin temperature lowers to about 8°C (46°F), there is a feeling of numbness, the first sign of impending frostbite.[93,94] Skin will begin to freeze at a temperature slightly lower than the freezing point of water because of the

TABLE 6 *Patterns and Significance of Tracer Uptake in Multiphase Bone Scintigraphy Applied in Frostbite Injury**

Category	Tracer Phase			Physiologic Significance
	Blood Flow (1–60 sec postinjection)	Soft Tissue (3–10 min postinjection)	Delayed (2–4 h postinjection)	
1	Normal	Normal	Normal	• Completely viable tissue
2	Increased	Increase	Normal to mildly increased	• Reactive hyperemia from reversible soft-tissue ischemia; bone viable.
3	Absent to diminished	Absent to diminished	Normal to mildly increased	• If early after injury, deep soft-tissue ischemia or hibernating tissue • If late after injury, deep soft-tissue infarction • Reversible bone ischemia
4	Absent	Absent	Absent	Deep soft-tissue and bone damage

*Modified from Millet et al.[68]

electrolyte content of the intracellular and extracellular fluids. Experimental studies indicate this freezing temperature varies somewhat among individuals but is generally near –4°C to –5°C (23°F).[92,95,96] Wet skin cools faster than dry skin and reaches a lower temperature,[96,97] so wetness should be avoided as much as possible. A small change in skin temperature (from –5°C to –8°C [23°F–18°F]) is estimated to increase frostbite risk from 5% to 95%.[92] Risk of frostbite appears to be minor if the air temperature is >–10°C (>14°F) but increases substantially at –25°C (–13°F).[92,95,98]

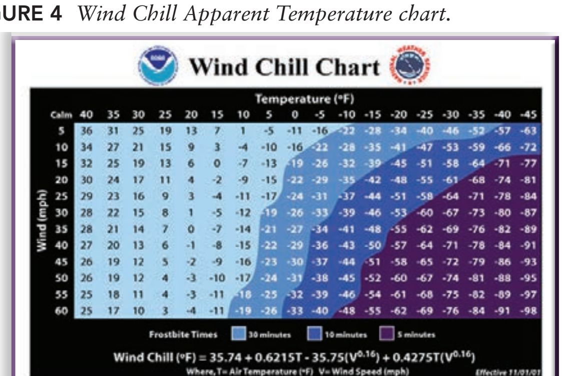
At a given temperature, an individual subjectively feels colder when exposed to wind. This is because the wind more quickly removes heat from exposed skin, resulting in more rapid skin cooling. The Wind Chill Chart (Figure 4) describes the effect of wind on the loss of body heat. It also estimates the risk of frostbite as a function of temperature and wind. The temperatures shown in the Wind Chill Chart are those resulting from heat loss from the skin in a wide range of decreasing temperatures and increasing wind speeds. The chart was developed from a model of the head, examining heat transfer under various temperature and wind conditions. Parts of the model were refined from data on individuals walking on a treadmill in various environmental conditions.[99,100] The model assumes a person is walking in an open field with a bare face. Wind speeds obtained from weather reports do not account for additional wind from activities such as running or skiing. The wind chill apparent temperature (i.e., a number on the chart) is always lower than the air temperature if there is wind. The decrease in apparent temperature becomes less over high wind speeds, whereas air temperature effects are relatively linear. The Wind Chill Chart generally corresponds with experimental data[91,92] and is an improvement on previous wind chill models,[101] but could be further improved.[102]

Clothing

Because clothing protects skin exposed to subfreezing temperatures by sequestering body heat,[103,104] clothing is considered the primary deterrent to cold injury. For the military, the Generation III Extended Cold Weather Clothing System (ECWCS) is a flexible clothing ensemble designed to provide insulation to reduce heat loss and provide ventilation for moisture to escape.[10] The Generation III ECWCS has 12 pieces and 7 layers designed for temperatures ranging from 4°C to –51°C (40°F to –60°F). It is compatible with other military systems (e.g., body armor, load-bearing equipment). Each part of the system can be used alone or with other parts of the ensemble to provide versatility in different environmental conditions. The layers in the ECWCS are shown in Figure 5. Layer 1 is the lightweight base layer (Undershirt and Drawers) worn next to the skin and constructed of polyester designed to remove excess moisture from the skin. Layer 2 is the Midweight Shirt and Drawers worn with the base layer or alone (to serve as a base layer) and is composed of polyester fleece. Layer 3 is the Fleece Cold Weather Jacket worn underneath shell layers (described below) or as an outer layer on moderately cool days. Layer 4 is the Wind Cold Weather Jacket, which is a minimal outer layer made of lightweight, wind-resistant, and water-repellent materials designed to assist in the removal of moisture from the skin. Layer 5 is the Soft Shell Cold Weather Jacket and Trousers, an outer layer designed for use in moderate to cold weather and composed of stretchable and water resistant materials. Layer 6 is the Extreme Cold/Wet Weather Jacket and Trousers, which provide a waterproof barrier, composed of Gore-Tex for use in prolonged hard rain and cold/wet conditions. Level 7 is the Extreme Cold Weather Parka/Trousers designed for use in static operations in extreme cold conditions and is highly water and wind resistant, with high loft insulation.[10]

For foot protection in cold weather, the current military boots are the Intermediate Cold/Wet Boot (Figure 6A) and the Extreme Cold Vapor Barrier Boot (Figure 6B). The Intermediate Cold/Wet Boot is waterproof and consists of leather with a removable Gore-Tex liner. It is designed for military personnel operating in cold and wet environments with temperatures between 20°C and –10°C (between 68°F and 14°F).[105,106] The Extreme Cold Vapor Boot was originally developed during the Korean War and has since been modified several times. The outer and inner layers are composed of wool insulation sandwiched between two layers of seamless rubber. The boot

FIGURE 4 *Wind Chill Apparent Temperature chart.*


Wind Chill Chart

Wind (mph) \ Temperature (°F): Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
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

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

Source: https://www.weather.gov/safety/cold-wind-chill-chart

FIGURE 5 *The seven layers of the Extended Cold Weather Clothing System, Generation III.*

Source: https://ciehub.info/clothing/CW/ECWCS/GEN3.html

FIGURE 6 *Boot and Hand Protection Systems for Cold Weather. Intermediate Cold/Wet Boot* **(A)**, *Extreme Cold Vapor Barrier Boot* **(B)**, *Generation 3 Modular Glove System* **(C)**.

Sources: **(A)** https://ciehub.info/clothing/footwear/BootsICW.html. **(B)** https://upload.wikimedia.org/wikipedia/commons/8/8d/White_Bata_Bunny_Boots.jpg (photo credit Randall McNair). **(C)** https://soldiersystems.net/2016/01/29/post-shot-show-wrapup-outdoor-research-glove-system/. The one glove system is shown twice.

is designed prevent moisture from rain or melting snow from entering the boot while retaining body heat. It is rated for temperatures down to –51°C (–60°F). Because the boot is entirely sealed between the two rubber layers, an air valve is provided on the side of the boot to equalize air pressure and prevent the boot from rupturing at high altitude. There is a wedge on the back for military ski and snowshoe bindings.[9,107] The Army is currently working on improvements to this boot, based on new technologies.

For protection of the hands, the Generation 3 Modular Glove System consists of 11 different gloves and mitts, shown in Figure 6C. Four of these are liners meant to be worn under other gloves/mitts to increase warmth but can be worn on their own. Two items are Combat Gloves designed to protect against impact and abrasion. Four items are outer layers designed to be worn over liners and/or gloves for extreme wet and cold conditions. The gloves and mitts have design features that assist in enhancing grip, aid in the use of mobile devices, and allow shooting firearms.[108] The Project Manager for Soldier Clothing and Individual Equipment recently issued a request for proposals for the development of a new modular glove system adequate for temperatures 40°F to –60°F.[109]

There are several methods of determining the amount of clothing insulation necessary to protect against cold injury,[110,111] but the most recent development for military purposes is the computer software application Cold Weather Ensemble Decision Aid (CoWEDA).[112] The CoWEDA model is generally based on maintaining skin temperature >5°C (>41°F) because below this value, pain, numbness, and reduced tactile sensation are severe, and the risk of cold-weather injury increases.[93,94,113] The effects of physical activity are considered in the model because activity increases body heat and lowers insulation requirements, although activity of sufficient intensity will also produce sweat, which can reduce the effectiveness of clothing. The model considers the insulation and moisture retention/dissipation properties of clothing available in the US military inventory. Figure 7 shows a screen shot of the CoWEDA user interface. The user selects the military clothing ensemble, environmental conditions, and anticipated physical activity. There are preset clothing ensemble selections, but military clothing can also be individually selected for five body regions, including the head, upper body, hands, lower body, and feet. The user can also input the environmental conditions, including air temperature, humidity, and wind speed. A drop-down menu has a list of military-related physical activities (i.e., guard duty, walking with load, exercise, lifting and carrying artillery shells). Outputs (i.e., results) include potential for frostbite in exposed skin, as well as covered feet and hands. The model has been validated against actual skin temperatures among individuals exposed to 0°C to –40°C (32°F to –40°F) and found to adequately predict actual skin temperatures during rest and moderate treadmill activity exercise.[112,114]

FIGURE 7 *Screen shot of the Cold Weather Ensemble Decision Aid (CoWEDA).*

Source: https://www.researchgate.net/figure/Cold-Weather-Ensemble-Decision-Aid-CoWEDA_fig1_331993742.

Physical Activity

Physical activity increases the metabolic rate and produces heat, which can provide additional protection against frostbite. However, warming effects of physical activity differ depending on the anatomic location and wind conditions. Compared with no exercise, relatively modest exercise (50% VO_2 max) increases skin temperature of the hands, fingers, and nose under low wind speeds.[115–117] However, exercise is less effective in increasing temperature under higher wind speeds. For example, when wind speeds were <2 mph and individuals were walking on a treadmill at 1.7 mph with a 6% incline, finger and nose temperatures were higher than when walking at this speed with no incline. However, when wind speeds were 11.2 mph, there was only a modest difference in finger temperatures between the two exercise intensities, although nose temperature was higher with more intense exercise. The higher exercise intensity had little effect on cheek or forehead temperatures at any wind speed.[116,117]

CIVD is also affected by exercise and physical training. Physical activity considerably increased the number of CIVD cycles and the number of individuals who experienced CIVD.[118] Exercise training (5 days/wk, 4 weeks, 50%VO_2max) increased the number of rewarming cycles and the average skin temperature of the fingers when exposed to cold.[119]

Other Prevention Techniques

Army Technical Bulletin Medicine 508[11] provides additional recommendations for prevention of frostbite; these are shown in Table 7.

Conclusion

Frostbite is a risk whenever temperatures are <0°C (32°F). Prevention is primarily based on an understanding of the clothing systems available to prevent cold-related injuries and the fact that physical activity can raise body temperature. If frostbite does occur and the patient can be sequestered in a warm environment, treatment involves rapid rewarming in a whirlpool bath (preferred) or rewarming with another human body. Imaging techniques to determine the depth of the injury are available in the field, with more sophisticated techniques available in hospital settings. Prevention of cold-weather injuries is a command responsibility, with medical planners integrated into planning decisions.

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TABLE 7 *List of Recommended Prevention Measures to Decrease Frostbite Risk**

Frostbite Risk Level	Prevention Measures
Low	• Increase surveillance with self and buddy checks
	• Wear appropriate layers and wind protection for work intensity
	• Cover exposed flesh if possible
	• Wear vapor barrier boots <0°F
	• Avoid sweating
High	• Mandatory buddy checks every 20–30 min
	• Wear ECWCS or equivalent and wind protection, including head, hands, feet, face
	• Cover exposed flesh
	• Wear vapor barrier boots <0°F
	• Provide warming facility
	• Avoid sweating
Severe	• Mandatory buddy checks every 10 min
	• Wear ECWCS or equivalent and wind protection, including head, hands, feet, face
	• Wear vapor barrier boots
	• Provide warming facility
	• Work in groups of at least two personnel
	• No exposed skin
	• Stay active
	• Avoid sweating
Extreme	• Be ready to modify activity because of extreme risk
	• Wear ECWCS or equivalent and wind protection, including head, hands, feet, face
	• Wear vapor barrier boots
	• Provide warming facility
	• Keep task duration as short as possible
	• Work in groups of at least two personnel
	• No exposed skin
	• Stay active
	• Avoid sweating

*From US Army Technical Bulletin MED 50811
ECWCS + Extended Cold Weather Clothing System

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Additional Resources

Cold Injury Prevention, Cold Weather Causality and Injuries: https://phc.amedd.army.mil/topics/discond/cip/Pages/Cold-Weather-Casualties-and-Injuries.aspx

TB MED 508, Prevention and Management of Cold-Weather Injuries (technical bulletin): https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=82441

TM 0-8415-236-10, Extended Cold Weather Clothing System Generation III (ECWCS GEN III) (technical manual): https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=84917

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