Unlike other animals that live outside the tropics, humans are susceptible to peripheral cold injuries. The highest homeostatic priority is to maintain the body’s core temperature. This is accomplished through peripheral vasoconstriction and shunting, which prevent adequate heat distribution to the extremities. As a result, failure to achieve adequate protection from the environment results in injuries that are usually preventable.1-3

Peripheral cold injuries include both freezing and nonfreezing syndromes, which may occur independently or in conjunction with systemic hypothermia.4 Frostbite is the most common freezing injury.5 Trench foot and immersion foot are nonfreezing injuries that result from exposure to wet cold.6 Nonfreezing injury that usually occurs after exposure to dry cold is termed chilblains (pernio).7

The incidence and severity of frostbite correlate with predisposing factors as well as with the degree of cold stress. Most cases of civilian frostbite result from exposure to cold by individuals who have not given due consideration to risk factors for cold injury.8,9 Well-equipped ascents of the world’s highest peaks have been completed without cold injury when appropriate steps have been taken to address these factors.10,11 An increase in outdoor recreational activities has increased the number of people exposed to severe cold conditions.12,13 Unsheltered homeless people are no longer the most likely group at risk in areas with moderate climates.14

Military history is replete with accounts of the effects of cold injury on combat troops.15,16 Amputations and time lost to local cold injuries in both world wars and the Korean conflict were extensive. Trench foot was common among Argentine and British forces in the Falkland Islands.4,17

Napoleon’s Surgeon General, Baron Larrey, first recorded the disastrous effects of the freeze-thaw-refreeze cycle.18 During the 1812 to 1813 Russian invasion and retreat, soldiers would acutely thaw frozen extremities directly over open fires. The subsequent refreeze further increased tissue destruction. Unfortunately, the resultant gangrene was misattributed to this rapid thawing of frostbite and trench foot injuries. Therefore, gradual thawing, often including friction massage with snow, remained the standard treatment regimen until the 1950s.19,20 In 1961, Mills ultimately popularized rapid warm immersion rewarming after extensive experience with severe Alaskan frostbite cases.20,21

**PRINCIPLES OF DISEASE**

**Physiology**

Human cold stress should induce adaptive behavioral reactions such as an attempt to find heat or shelter. In addition, complex endocrinologic and cardiovascular physiologic responses are engaged. Peripheral cooling of the blood activates the preoptic anterior hypothalamus. This central thermostat orchestrates temperature regulation. This dynamic process encompasses catecholamine release, thyroid stimulation, shivering thermogenesis, and peripheral vasoconstriction.

Cutaneous circulation is one of the keys to maintenance of thermoneutrality. Baseline cutaneous circulation greatly exceeds the nutritional requirements. This reflects the skin’s “radiator” function to maintain thermostability. Cutaneous blood flow in the euthermic 70-kg human averages 200 to 250 mL/min. Heat stress causes vasodilation that can increase this amount to 7000 mL/min. In contrast, extreme cold-induced vasoconstriction reduces flow tenfold to less than 50 mL/min.

During cold stress, peripheral vasoconstriction limits radiant heat loss. Acral skin structures (fingers, toes, ears, nose) contain a plethora of arteriovenous anastomoses. These arteriovenous anastomoses shut down in the cold, causing drastic reductions in blood flow. This “life-versus-limb” mechanism reflects the homeostatic attempt to prevent systemic hypothermia.

In contrast to heat exposure, humans do not appear to display significant physiologic adaptation to the cold. Exposure of extremities to temperatures down to 15° C results in maximal peripheral vasoconstriction with minimal blood flow. Continued exposure to progressively colder temperatures down to 10° C produces the “hunting response,” which is cold-induced vasodilation.22 These periods of vasodilation, recurring in 5- to 10-minute cycles, interrupt vasoconstriction and serve to protect the extremity. Eskimos as well as Lapps and others of Nordic extraction are capable of stronger cold-induced vasodilation than that in individuals from tropical regions. Measurement of the speed of cold-induced vasodilation may help predict an individual’s risk for cold injury.23 There is evidence of adaptation rather than pure genetic control.24

**Pathophysiology**

The pathologic phases that occur with local cold injury often overlap and vary with the extent and rapidity of the cold response
Box 139-1  Freezing Injury Cascade

**Prefreeze Phase**
- Superficial tissue "cooling"
- Increased viscosity of vascular contents
- Microvascular constriction
- Endothelial plasma leakage

**Freeze-Thaw Phase**
- Extracellular fluid ice crystal formation*
- Water diapedesis across cell membrane
- Intracellular dehiscence and hyperosmolarity
- Cell membrane denaturation or disruption
- Cell shrinkage and collapse

**Vascular Stasis and Progressive Ischemia**
- Vasospasticity and stasis coagulation
- Arteriovenous shunting
- Vascular endothelial cell damage or prostanoid release
- Interstitial leakage or tissue hypertension
- Necrosis, demarcation, mummification, or slough

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*Extremely rapid cooling produces more initial intracellular than extracellular ice crystallization.

(Floor 139-1). Frostbite occurs when the tissue supercools well below 0°C. The required temperature is at least −4°C and may be as low as −10°C.

There are two putative mechanisms of tissue injury: architectural cellular damage from ice crystal formation and microvascular thrombosis and stasis. In the prefreeze phase, tissue temperatures drop below 10°C and cutaneous sensation is lost. Before ice crystal formation, microvascular vasocostriction occurs along with endothelial leakage of plasma into the interstitium. Radiation and conduction of heat from deeper tissues prevent crystallization until the skin temperature drops well below 0°C. In the freeze-thaw phase, the timing, location, and rate of ice crystal formation depend on the exposure circumstances. In addition to ambient temperatures, wind and moisture increase the freezing rate.

During usual exposure conditions, ice crystal formation initially occurs extracellularly. This results in diapedesis of water exiting the cell to maintain osmotic equilibrium. Cellular dehydration increases the intracellular osmolarity and electrolyte concentrations. When approximately one third of the cellular volume is lost, cellular collapse and death result. These may occur with or without direct architectural damage from the crystals. Extracellular crystallization also increases the tissue pressure on cell membranes and surrounding vascular structures. Sludging, stasis, and cessation of flow occur at the capillary level.

The third phase, progressive microvascular collapse, first affects venules and then arterioles. Red blood cells sludge and form microthrombi during the first few hours after the tissues are thawed. Factors adversely affecting flow include hypoxic vasospasm, hyperviscosity, and direct endothelial cell damage. Anaerobic metabolism subsequently extends the surrounding injury. Tissues are deprived of nutrients and oxygen. Ultimately, plasma leakage and arteriovenous shunting result in thrombosis, increased tissue pressure, ischemia, and necrosis.

Some direct skin injury is reversible. For example, frozen skin grafted to a normal site can survive. The histopathology of frostbite suggests that some changes in the epidermis are primary and some reflect damage to the endothelial cells. During initiation of rewarming, these tissues are revitalized.

An additional insult, progressive dermal ischemia, is partially mediated by thromboxane. Fluid analysis of clear vesicles identifies prostaglandins. When subdermal vascular plexuses are injured, hemorrhagic blisters develop that also contain these prostanoids.

The arachidonic acid breakdown products released from underlying damaged tissue into the blister fluid include both prostaglandins and thromboxane. These mediators produce platelet aggregation, vasocostriction, and leukocyte immobilization.

The ultimate determinant of progressive tissue damage appears to be injury to the microvasculature. Endothelial cells are the tissue most susceptible to freezing injury. After thawing, the vasculature is patent only temporarily. Platelet and erythrocyte aggregates promptly clog and distort the vasculature. Intense vasocostriction coupled with arteriovenous shunting occurs at the interface between normal and damaged tissue. The injured viable vasculature remains distorted. Local arteritis, medial degeneration, and intimal proliferative thickening are seen. Nerve and muscle tissues are also more susceptible than connective tissue to cold injury. For example, nonviable hands and feet can be moved after thawing if the tendons are intact.

Edema progresses for 48 to 72 hours after tissue is thawed. Leukocyte infiltration, thrombosis, and early necrosis become apparent as this edema resolves. The dry gangrene carapace of frostbite is superficial in comparison to arteriosclerosis-induced, full-thickness gangrene. Although the historical surgical aphorism was “frostbite in January, amputate in July,” advances in imaging modalities can accelerate the identification of the demarcation between viable and nonviable tissue.

Box 139-2  Predisposing Factors

<table>
<thead>
<tr>
<th>Physiologic</th>
<th>Environmental</th>
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<tbody>
<tr>
<td>Genetic</td>
<td>Ambient temperature</td>
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<tr>
<td>Core temperature</td>
<td>Humidity</td>
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<tr>
<td>Previous cold injury</td>
<td>Duration of exposure</td>
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<tr>
<td>Acclimatization</td>
<td>Wind chill factor</td>
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<tr>
<td>Dehydration</td>
<td>Altitude and associated conditions</td>
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<tr>
<td>Overexertion</td>
<td>Quantity of exposed surface area</td>
</tr>
<tr>
<td>Trauma: multisystem, extremity</td>
<td>Heat loss: conductive, evaporative</td>
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<tr>
<td>Dermatologic diseases</td>
<td>Aerosol propellants</td>
</tr>
<tr>
<td>Physical conditioning</td>
<td>Cardiovascular</td>
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<tr>
<td>Diaphoresis, hyperhidrosis</td>
<td>Hypotension</td>
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<td>Hypoxia</td>
<td>Athrosclerosis</td>
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<tr>
<td>Mechanical</td>
<td>Arteritis</td>
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<tr>
<td>Constricting or wet clothing</td>
<td>Raynaud’s syndrome</td>
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<tr>
<td>Tight boots</td>
<td>Cold-induced vasodilation</td>
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<tr>
<td>Vapor barrier, alveolite liners</td>
<td>Anemia</td>
</tr>
<tr>
<td>Inadequate insulation</td>
<td>Sickle cell disease</td>
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<td>Immobility or cramped positioning</td>
<td>Diabetes</td>
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<tr>
<td>Psychological</td>
<td>Vasocostricators, vasodilators</td>
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<tr>
<td>Mental status</td>
<td>Intoxicants</td>
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<td>Fear, panic</td>
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<td>Attitude</td>
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<td>Fatigue</td>
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<td>Intense concentration on tasks</td>
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<td>Hunger, malnutrition</td>
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<td>Intoxicants</td>
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</table>

Predisposing Factors

The extent of peripheral cold injury is determined by the type and duration of cold contact with the skin (Box 139-2). Predisposing risks include physiologic, mechanical, psychological, environmental, and cardiovascular factors.

Any conditions affecting judgment can jeopardize the physiologically tropical human. In urban settings, cold injuries are often attributed to psychiatric impairment or intoxication, primarily
ethanol intoxication. Ethanol also produces peripheral vasodilatation, which increases heat loss. Blunting of self-protective instincts can cause people to fail to undertake appropriate adaptive maneuvers to minimize exposure to cold.

Although air alone is a poor thermal conductor, associated cold and wind (wind chill index) markedly increase heat loss. Direct skin contact with good thermal conductors such as metal, water, and volatile liquids affects the extent and rapidity of tissue destruction. Commercial aerosol spray propellants, such as propane and butane, and carbon dioxide in fire extinguishers are potentially hazardous. Liquid oxygen and Freon can also cause frostbite. Overenthusiastic application of standard ice packs in the treatment of soft tissue injuries can also result in tissue loss. Cryotherapy is commonly prescribed in sports medicine. In addition to improper use of cold packs, vapor coolant sprays such as chloroethane can cause frostbite.

**CLINICAL FEATURES**

**Symptoms and Signs**

“Frostnip” is a superficial cold insult manifested by transient numbness and tingling that resolves after rewarming. This does not represent true frostbite because no tissue destruction occurs.

The symptoms of frostbite usually reflect the severity of the exposure. The most common presenting symptom is numbness, found in more than 75% of patients. All patients have some initial sensory deficiency in light touch, pain, or temperature. Anesthesia is produced by intense vasoconstrictive ischemia and neurapraxia. Acral areas and distal extremities are the usual insensate sites. The distal extremities—the fingers, toes, nose, ears, and penis—are specific locations at risk. Patients often complain of clumsiness and report a “chunk of wood” sensation in the extremity. The history of complete acute anesthesia in a painful cold digit suggests a severe injury.

Classically, the initial presentation of frostbite is deceptively benign. Most patients do not arrive in the emergency department with frozen, insensate tissue. Frozen tissues often appear mottled or violaceous-white, waxy, or pale yellow. In severe cases, the examiner will not be able to roll the dermis over bone prominences. Rapid rewarming results in an initial hyperemia, even in severe cases. After thawing, partial return of sensation should be expected until blebs form.

Favorable initial symptoms include normal sensation, warmth, and color. Soft, pliable subcutaneous tissue suggests a superficial injury. A residual violaceous hue after rewarming is ominous. Early formation of clear large blebs that extend to the tips of the digits is more favorable than delayed appearance of smaller hemorrhagic blebs. These dark vesicles are produced by damage to the subdermal vascular plexuses. Vesicles and large bullae usually form in 1 to 24 hours.

Lack of edema formation suggests significant tissue damage. Post-thaw edema usually develops in less than 3 hours. In severe cases, frostbitten skin forms an early black, dry eschar until mummification and apparent demarcation.

Histologically, frostbite, like burns, has been classified into degrees of injury. Anesthesia and erythema are characteristic of first-degree frostbite. Superficial vesiculation surrounded by edema and erythema is considered second-degree frostbite. Third-degree frostbite produces deeper hemorrhagic vesicles. Fourth-degree injuries extend into subcuticular, osseous, and muscle tissues.

Classification by degrees is often incorrect in relation to the actual severity of the frostbite and thus therapeutically misleading. Mills suggests two simple retrospective classifications. Superficial or mild frostbite does not entail eventual tissue loss, whereas deep or severe frostbite does result in tissue loss. As a result, it is not feasible to predict, on presentation, the eventual tissue loss. Another classification attempts to establish severity on the basis of clinical features coupled with early bone scan results. Significant pain usually accompanies reestablishment of perfusion. With partial tissue destruction, intermittent pain may be noticed during ongoing exposure. The dull continuous ache evolves into a throbbing sensation in 48 to 72 hours. This often persists until tissue demarcation several weeks to months later. Nonfreezing cold injury occurs when tissue fluids have not frozen. Chilblain (pernio) is a mild form of cold injury that often follows repetitive exposure. These “cold sores” appear less than 24 hours after exposure and usually affect facial areas, the dorsa of the hands and feet, and the pretilial areas. Young women with a history of Raynaud’s phenomenon or systemic lupus erythematosus or with antiphospholipid antibodies are especially at risk. Persistent vasospasm and vasculitis result in burning, pruritus, erythema, and mild edema. Plaques, blue nodules, and ulcerations can develop and last 1 to 2 weeks.

The other common nonfreezing cold injury is trench foot (immersion foot). This remains a significant threat during recreational activities and military expeditions in cold, wet climates. Trench foot is produced by prolonged exposure to wet cold at temperatures above freezing. It usually develops slowly during several days and results in neurovascular damage in the absence of ice crystal formation. Immersion foot commonly develops while a person is wearing sweat-dampened or neoprene socks, vapor-barrier boots, or constrictive gaiters. Patients who soak their feet for hours each night in cool water for pain relief are also at risk.

The clinical presentation varies. Most patients’ symptoms include cool, pale feet that are numb or tingle. Later the feet appear cyanotic, cold, and edematous. Often, numbness and leg cramping are present. The clinical hallmark is that after rewarming, the skin remains erythematous, dry, and very painful to touch. Rubor on dependency and pallor on elevation are caused by vasomotor paralysis. Infrared thermography in response to a cold stress may support the diagnosis and assess its severity.

Bullae that are indistinguishable from those seen with frostbite commonly develop. Vesiculation may proceed to ulceration and liquefaction gangrene in severe cases. Protracted symptoms of pain during weightbearing, cold sensitivity, and hyperhidrosis often last for years. Prevention of trench foot often requires continual drying of socks.

**DIAGNOSTIC STRATEGIES**

Many ancillary diagnostic imaging techniques attempt to grade the severity of injury. Unfortunately, none consistently and accurately predicts tissue loss at the time of initial examination.

Routine baseline radiographs should be obtained. Follow-up radiographs will begin to demonstrate specific frostbite abnormalities 4 to 10 weeks after injury. Intravenous isotope studies have had mixed success experimentally and clinically. In one study, triple-phase bone scans performed 2 days after cold injury demonstrated ischemic tissue at risk. Delayed bone scans in 7 to 10 days can image deep tissue and bone infarction. The absence of radionuclide uptake even after 10 days, however, does not reliably predict the eventual need for amputation. The patient should be advised that accurate prediction of eventual tissue loss is difficult. As an ancillary tool, scintigraphy predicts the eventual demarcation line better than thermography does. Scintigraphy as early as day 2 may predict tissue loss and monitor the efficacy of treatment.

Large-vessel angiography does not assess the microvasculature at presentation because of vasospasm. Use of papaverine may help distinguish vasospasm from frostbite sludging and vascular injury. Transitory vascular instability often lasts 2 to 3 weeks. Angiography does facilitate evaluation of associated traumatic or chronic...
vascular abnormalities. Doppler ultrasonography and digital plethysmography are insensitive but may help determine the need for sympathetic blockade.

In clinical practice, magnetic resonance imaging and magnetic resonance angiography may be superior to technetium bone scanning. In one study, the clear-cut line of demarcation was noted before clinical demarcation. Magnetic resonance imaging of developing hyaline cartilage can demonstrate physeal injury, which has the largest impact on longitudinal growth. 43

MANAGEMENT

Field rewarming of frozen tissue is rarely practical. If possible, constricting or wet clothing should be removed and affected areas insulated and immobilized. Friction massage is not efficacious and increases tissue loss. Frozen parts should be kept away from dry heat sources such as heated forced air during transport.

A relationship often exists between the length of time that tissue is frozen and the ultimate extent of cellular damage. Rewarming should not be initiated in the field, however, if there is any potential for interrupted or incomplete thawing. Tissue refreezing is disastrous, and it is preferable to ambulate to safety on frozen extremities if rescue will be delayed.

When evacuation is not possible, rapid field rewarming, preferably in water at 37 to 39°C, may be the only option. Logistic considerations include the risks to the party, the availability of shelter and necessary equipment, and the anticipated mode of eventual transportation.

Emergency Department

Prethaw

Pertinent history regarding the ambient temperature, wind velocity, and duration of exposure should be obtained. The type of apparel worn, the circumstances surrounding rescue, and the presence of preexisting cardiovascular or neurologic diseases that could affect tissue loss should be noted. 44

After the core temperature has been stabilized and associated conditions have been addressed, rapid thawing of frostbitten extremities should be initiated. Treatment should not be delayed while the results of laboratory and radiographic studies are awaited. Most patients have some degree of dehydration and benefit from crystalloid administration. Poor oral intake and hypothermia-induced cold diuresis further increase blood viscosity and sludging.

Thaw

Frozen or partially thawed tissue should be rapidly and actively rewarmed by immersion in gently circulating water that is carefully maintained at a temperature of 37 to 39°C by thermometer measurement. 20 Marginal tissue can suffer thermal injury when the water temperature exceeds 42°C. Although a circulating tank is ideal for arms or legs, a large container suffices for the hands or feet. Water warmer than 39°C is less well tolerated and causes more pain. Care should be taken to prevent the frostbitten area from bumping or rubbing against the side of the container.

Rewarming should be continued until the part feels pliable and distal erythema is noted. This usually requires 10 to 30 minutes of submersion. Encourage active gentle motion of the part by the patient during rewarming but avoid direct tissue massage.

Parenteral analgesia is often indicated during rewarming of deep frostbite. Reperfusion may be intensely painful. It produces throbbing, burning pain and tenderness. A common error is premature termination of rewarming, which results in a partial thaw.

Sensation is often diminished after thawing until it disappears with bleb formation.

Patients with completely frozen extremities are usually hypothermic and at risk for significant fluid and electrolyte fluxes during rewarming. The acute thawing of large amounts of distal musculature extinguishes peripheral vasoconstriction. This results in the sudden return of cold, hyperkalemic, acidic blood to the central circulation. This produces “core temperature afterdrop,” which is dysrhythmogenic. In the most severe cases, extracorporeal rewarming should be considered for management of these massive metabolic and electrolyte derangements (Box 139-3).

Post-thaw

The injured extremities should be kept elevated to minimize edema formation. Sterile dressings should be applied and involved areas handled gently. Persistent cyanosis in the extremities after a complete thaw may reflect increased fascial compartment pressure. Because of the cold-induced anesthesia, other occult soft tissue injuries are often not appreciated by the patient or physician. Tissue pressures should be monitored carefully, although decompressing fasciotomies are usually not necessary during the initial treatment rendered in the emergency department.

The clinical role of thromboxane inhibition in frostbite seems to be limited. Thromboxane inhibition does not appear to result in additional clinically significant tissue salvage. In one experimental model, methimazole did not improve tissue survival even when therapy was initiated immediately. 45 Progressive secondary dermal ischemia is addressed by attempts to limit the accumulation of the products of arachidonic acid breakdown. Topical aloe vera (Dermaide) every 6 hours is a specific thromboxane inhibitor when it is applied directly to frostbitten areas but has not definitively been proven to salvage tissue. 29 Other alternatives include topical antibiotic ointment. Theoretically, oral ibuprofen appears preferable to oral aspirin. Although both agents inhibit the arachidonic acid cascade, ibuprofen also produces fibrinolysis. Parenteral ketorolac can also be considered.

Box 139-3 Emergency Department Rewarming Protocol

Prethaw

Assess Doppler pulses and appearance
Protect part—no friction massage
Stabilize core temperature
Address medical and surgical conditions
Rehydrate patient
Prevent partial thaw and refreeze

Thaw

Provide parenteral ketorolac and opiate analgesia as needed
Administer ibuprofen 400-600 mg every 6 hours orally
Immerse part in circulating water that is thermometer monitored at 37 to 39°C
Encourage gentle motion of part

Post-thaw

Dry and elevate part
Aspirate or débride clear vesicles
Débride broken vesicles and apply topical antibiotic or sterile aloe vera ointment every 6 hours
Leave hemorrhagic vesicles intact
Consider tetanus and streptococcal prophylaxis
Provide hydrotherapy at 37°C three times a day
Consider phenoxybenzamine in severe cases
Consider imaging, angiography, and thrombolysis
Obtain admission and serial photographs
antithrombotic and vasodilation treatment regimens, although most lack adequate controls. Many of these studies were conducted before the elucidation of some of the pathophysiologic consequences of frostbite. Triple-phase bone scans have demonstrated that thrombolytic agents may restore some flow to severely frostbitten limbs.

**Thrombolytic Therapy**

Thrombolytic therapy may address the primary residual pathophysiologic changes if the cumulative cold-ischemia time (frozen time) and warm-ischemia time (thawed and unperfused) is not excessive. In one retrospective study, intravenous tissue plasminogen activator and heparin reduced predicted digit amputations in severe frostbite.42 Nonresponders had more than 24 hours of exposure, more than 6 hours of warm ischemia, or multiple freeze-thaw cycles. In another study, intra-arterial tissue plasminogen activator decreased the incidence of amputations when it was administered within 24 hours.49

A screening and treatment tool is proposed for thrombosis.50,51 If the flow is absent after thawing and both the cold-exposure and warm-ischemia times are each less than 24 hours, angiography is performed with intra-arterial vasodilators. Nitroglycerin and papaverine have both been used successfully. If flow is not reestablished, continuously infuse intra-arterial catheter-directed tissue plasminogen activator to a maximum dose of 1 mg/hr. Heparin is administered concurrently and continued for 72 to 96 hours.51,52 A second alternative approach combines systemic intravenous thrombolytic therapy with subsequent vascular evaluation by technetium scanning.

Low-molecular-weight dextran may inhibit intravascular cellular aggregation. Animal models suggest that low-molecular-weight dextran is not harmful. Pentoxifylline, a phosphodiesterase inhibitor, may decrease blood viscosity and increase tissue oxygenation.53 Its ability to increase red blood cell flexibility facilitates revascularization and may enhance tissue survival. The suggested dosage is 400 mg three times daily for 2 to 6 weeks.54

Various anti-inflammatory drugs and other agents have not been conclusively evaluated. These include steroids, nonsteroidal anti-inflammatory drugs, dipyridamole, dimethyl sulfoxide, non-ionic detergents, and calcium channel blockers.55,56 A long-acting alpha-blocker, phenoxybenzamine, may decrease vasospasm while increasing peripheral blood flow. The dosage starts with 10 mg/day to a maximum of 60 mg/day. With this agent, adequate hydration is necessary to prevent orthostatic hypotension.

Hyperbaric oxygen produces vasoconstriction and subsequently reduces cutaneous blood flow. A small number of patients report a temporary flush and increased limb motion, but this appears to depend on the elapsed time interval after injury. Hyperbaric oxygen has the potential to accelerate demarcation. There are insufficient data to assess the potential value of hyperbaric oxygen therapy for tissue salvage in severe frostbite.57,58

**Sympathectomy**

The theoretic benefits of sympathectomy include relief of painful vasospasm, decreased edema, and increased tissue salvage. Long-term vasodilation could theoretically protect against repeated cold injury and some of the degenerative sequelae of frostbite. The value of these benefits is speculative. Epidural spinal cord stimulation combined with conventional treatment may reduce pain and conserve tissue.

A chemical sympathectomy results from direct injection of an agent such as reserpine into an artery. Common injection sites include the radial, brachial, and femoral arteries. This injection produces local depletion of arterial wall norepinephrine for 2 to

**Adjunctive Treatment**

Numerous ancillary modalities have been suggested for frostbite.48 Capillary flow ceases early after cold injury, whereas thrombosis proceeds.30,40 This observation has led to multiple experimental

**Figure 139-1.** Frostbite with clear vesiculations. (Courtesy Bill Mills, MD.)

**Figure 139-2.** Severe frostbite with early hemorrhagic vesicles. (Courtesy Bill Mills, MD.)

Frostbite blister management varies widely. Recommended options for large clear blisters include leaving them intact, débride-ment, and aspiration (Fig. 139-1). Although most clinicians débride broken blisters, many prefer to aspirate intact clear blisters rather than to débride them. In contrast, if hemorrhagic blisters are débrided, secondary desiccation of deep dermal layers appears to extend the injury (Fig. 139-2). In this case, aspiration is preferable to débridement.

In severe cases, parenteral penicillin may be indicated for streptococcal prophylaxis. Cultures and Gram’s stains of areas adjacent to the damaged tissue should be performed. Common organisms causing secondary infection include staphylococci, streptococci, and *Pseudomonas* species. Tetanus can also occur after frostbite. Tetanus prophylaxis should follow usual wound care guidelines.

Management of the chilblains syndrome is usually supportive. Nifedipine (20-60 mg daily) is an effective treatment of refractory perniosis.46,47 Topical or systemic corticosteroids have also been useful. Other options include oral pentoxifylline and limaprost, a prostaglandin E1 analogue.

**Figure 139-1.** Frostbite with clear vesiculations. (Courtesy Bill Mills, MD.)

**Figure 139-2.** Severe frostbite with early hemorrhagic vesicles. (Courtesy Bill Mills, MD.)
4 weeks. No significant systemic effects are appreciated with the recommended dose of 0.5 mg. This can be repeated in 2 to 3 days. Parenteral reserpine is not commercially available in the United States. There is angiographic documentation of temporary improvement in perfusion and vasospasm after chemical sympathectomy. When tissue is rapidly thawed, experimental attempts to demonstrate further enhancement of tissue salvage have failed. Intra-arterial reserpine may prove most useful in patients with residual pain after gradual thawing.

Iloprost, a prostacyclin analogue, also has vasodilatory properties that mimic a chemical sympathectomy. The risk of amputation is significantly lower in a controlled trial of patients with severe frostbite who received intravenous iloprost plus aspirin after thawing. Selected patients in this series with severe frostbite were also treated with recombinant tissue plasminogen activator. Forearm nerve blocks also produce in effect a chemical sympathectomy that increases finger skin temperature.

Early results with surgical sympathectomy were encouraging. Bouwman and colleagues performed unilateral surgical sympathectomy on 10 patients with bilateral matched frostbite injuries. Delayed protection against reinjury was one direct benefit. Ultimately, however, there was no increased tissue salvage. Mills observed that surgical sympathectomy produces a smoother initial clinical course but no long-term benefits, with the possible exception of decreased causalgia.

### DISPOSITION

Except in minor cases, all patients should be hospitalized to determine the extent of injury. Damaged tissues are best protected with loose sterile sheets and towels rather than with compressive dressings. Feet should be kept elevated under a protective cradle. Sterile cotton pledgets should be placed between the toes, and the hands may rest elevated on the chest.

Whirlpool hydrotherapy with an antiseptic should be performed two or three times daily for 20 to 30 minutes to débride dead tissue and to decrease the amount of bacterial colonization. Range-of-motion exercises should be encouraged during immersion. Severe cases may require position-of-function splinting. Hydrotherapy is continued as the eschar sloughs. During hospitalization, all vasoconstrictive agents, including nicotine, should be avoided. Vacuum-assisted closure therapy attracts wound edges centripetally, reduces tissue edema, and promotes angiogenesis in burns and complex wounds. With frostbite, it could prove beneficial to prevent grafting or amputation.

### SEQUELAE

Direct neuronal damage and residual abnormalities in sympathetic tone are responsible for most of the common symptomatic sequelae of frostbite. In a series of military patients with documented frostbite, 65% had long-term residual symptoms. Vasospasm with secondary cold intolerance is the other major sequela. Intermittent paresthesias resulting from ischemic neuritis are reported after the first week. The severity of this symptom often reflects the extent of tissue damage. Symptoms may persist for many months. Burning electric shock sensations are worse at night, after heat exposure, and on first returning to ambulation. Thermal perception is also altered. Hyperhidrosis suggests an abnormal sympathetic nervous system response and often is both a cause and an effect of frostbite.

Delayed cutaneous findings include nail deformities and pigmentation changes. Squamous and epidermoid cell carcinoma can occur. Osseous reabsorption and subchondral lytic defects develop months after the cold insult. In pediatric patients, concerns include premature fusion, destruction, and fragmentation of epiphyses.

Shortening of the distal phalanges is common. Frostbite arthritis also occurs, commonly 3 to 10 years later. Thumb sparing is a characteristic idiosyncrasy. Clenching of the fists can spare both thumbs and metacarpophalangeal joints. Identification of subchondral cysts after bone infarction differentiates frostbite arthritis from osteoarthritis. In severe cases involving extremity muscle compartments, rhabdomyolysis and subsequent renal failure are a concern. Continuous monitoring of serum muscle enzymes and urinalyses is warranted.

Surgical decisions regarding amputation are complex. The amount of tissue eventually salvaged often exceeds even optimistic initial estimates. Historically, the natural progression of demarcation, mummification, and eventual sloughing was allowed to occur. Advances in radiologic assessment of tissue viability are facilitating earlier surgical intervention. Free flap tissue transfer to salvage function after earlier débridement of soft tissues should be a consideration. Compared with grafts, flaps provide their own vascularity and are less dependent on the recipient bed.

Various neuropathic, musculoskeletal, and dermatologic sequelae of frostbite are listed in Box 139-4.

### KEY CONCEPTS

- Premature termination of thawing in 37 to 39°C water is a common error. Reperfusion of completely frozen tissue may be very painful and may require parenteral analgesia.
- The early formation of clear blebs is more favorable than delayed hemorrhagic blebs, which reflect damage to the subdermal vascularplexuses.
- The patient should be advised that accurate prediction of eventual tissue loss is not always possible at presentation, despite imaging.
- Thrombolytic agents may restore some flow to severely frostbitten limbs.

The references for this chapter can be found online by accessing the accompanying Expert Consult website.
References