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Frostbite: Prevention and Initial Management

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Abstract

Zafren, Ken. Frostbite: Prevention and initial management. *High Alt. Med. Biol.* 14:9–12, 2013.—Frostbite is a local freezing injury that can cause tissue loss. Historically, it has been a disease of wars, but it is a hazard for anyone who ventures outdoors in cold weather. Frozen tissue is damaged both during freezing and rewarming. Frozen tissue is numb. Rewarming causes hyperemia and is often painful. Blisters and edema develop after rewarming. Hard eschar may form with healthy tissue deep to the eschar. Frostbite can be classified as superficial, without permanent tissue loss, or deep, with varying degrees of permanent tissue loss, often less than appearances suggest. It can be difficult to predict the amount of tissue loss at the time of presentation and early in the subsequent course. Prevention is better than treatment. It may be advisable not to rewarm frozen extremities in the field, but spontaneous thawing is often unavoidable. Extremities that have thawed should be protected from refreezing at all costs. Once in a protected environment, extremities that are still frozen should be rapidly thawed in warm water. Therapy with aspirin or ibuprofen may be helpful, but evidence is limited. Thrombolytic treatment within the first 24 hours after rewarming seems to be beneficial in some cases of severe frostbite. Prostacyclin therapy is very promising.

Key Words: frostbite, cold injury, search and rescue, thrombolytic therapy, tPA, prostacyclin.

Introduction

Frostbite is a localized freezing cold injury. Throughout history, frostbite has been a disease of wars. It was first described by the Greeks during Xenophon's campaign in Armenia around 4000 BCE. Frostbite essentially eliminated Napoleon's army as a fighting force during the Russian invasion in 1812–1813. It caused over a million casualties in World Wars I and II and the Korean War (Mills 2001). Frostbite has continued to be a problem in cold-weather warfare into the twenty-first century, especially in mountainous areas such as the Karakoram Mountains in Central Asia.

Frostbite is a hazard not only for soldiers but also for mountaineers, skiers, and others who venture outdoors in cold weather for recreation or for work. Frostbite is also a danger for homeless or displaced persons, especially during natural disasters or forced migrations. Nonfreezing cold injuries, such as trench foot, can produce tissue damage but are not discussed in this review.

Cold injuries result from inadequate protection against a cold environment. Frostbite most frequently affects the hands and feet but can also occur on ears, nose, and cheeks. Rarely, frostbite can affect other parts of the body, including the cornea, buttocks and penis.

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Skin does not freeze until it cools to $-4°C$ or colder (Mazur 1970). Wind increases the rate at which skin cools but does not affect the temperature at which skin freezes (Wilson and Goldman 1970). Frostbite is rare at air temperatures above $-9°C$ (Danielsson 1996).

This review starts with a discussion of the pathophysiology of frostbite injury, clinical course, and classification based on prognosis. I then outline risk factors and prevention. I discuss field treatment, although limited. The key initial treatment in a clinic or hospital setting for extremities that are still frozen is rapid thawing in warm water. Once extremities have been thawed, meticulous wound care is critical. Adjunctive therapy with medications, including early use of tPA or prostacyclin, may be beneficial.

Pathophysiology

Freezing

The initial response to skin cooling is vasoconstriction, which helps defend core temperature against loss of heat via the skin. In the extremities, this is followed by cold-induced vasodilation (CIVD), also known as the "hunting response," which protects against cold injury at the cost of increased heat loss (Lewis 1941). The skin loses sensation and CIVD begins at about 10°C. As the skin cools further, blood viscosity increases, and there is microvasculature constriction with transendothelial leakage of plasma. Because skin requires super-cooling for ice crystal formation, freezing does not begin to occur until well below $-4°C$, in some cases as low as -10 or $-15°C$ (Mazur 1970). Except in the case of very rapid freezing, ice crystals form initially in the extracellular space (Meryman 1974). Increased extracellular osmotic pressure draws free water across the cell membrane causing intracellular water loss, hyperosmolality, and decreased cell volume accompanied by extracellular and intracellular electrolyte and acid-base disturbances with destruction of enzymes. Growing ice crystals may also damage cells directly. Cell membranes are damaged, as well. Damage to endothelium injures the microvasculature, causing most of the indirect injury to the tissue.

Rewarming

Rewarming may result in reperfusion injury (Manson, Jesudass et al. 1991). Large blisters, also known as "blebs," may appear due to vasodilation, edema, and vascular stasis. Prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) and thromboxane A_2 (TXA_2) are found in the blister fluid and have been implicated in platelet aggregation and thrombosis (Robson and Heggers 1981). Secondary vasospasm during the first 48 hours worsens tissue damage.

Clinical Course

During the freezing phase, the affected area may initially feel cold and then feel numb before all feeling is lost. Patients describe clumsiness and anesthesia, like "a block of wood." In some cases complete anesthesia occurs without any of the warning signs (Mills 2001). The tissue is cold to touch and appears waxy and mottled blue, "violaceous," or yellowish-white. The rewarming phase occurs when the frostbitten area thaws. This process is often painful. The affected area is blue-gray and is demarcated from normal tissue. After rapid rewarming, even the most severe cases exhibit an initial hyperemia. Blisters form in 1 hour to a few days. Large distal blisters with serous fluid suggest superficial injury. Small hemorrhagic blisters proximal to the interphalangeal joints indicate deep damage and likely tissue loss. Edema increases for 48–72 hours after thawing. If not broken, the blebs dry in four to ten days. Hard eschar may develop that suggests deep gangrene. However, in two to three weeks the eschar begins to fall off, revealing healthy granulation tissue.

Classification and Prognosis

In the past, frostbite was classified like burns as first through fourth degree. This classification is confusing, difficult to apply, and has misled many medical providers into treating frostbite injuries as if they were burns, with devastating results. It has largely been replaced by a simpler scheme: superficial frostbite, without tissue loss, and deep frostbite, in which tissue loss is expected (Mills 2001). Frostnip is a very superficial form of local freezing injury characterized by numbness and tingling that resolve after rewarming. Superficial frostbite may initially mimic deep frostbite. In deep frostbite, it is often hard to predict the amount of tissue loss, but it is often less than appearance would suggest.

Since it can be difficult to predict the extent of tissue loss, frostbite has been traditionally managed by allowing demarcation to occur over 6 weeks to 3 months. Tissue is then amputated or allowed to auto-amputate unless infection necessitates earlier surgical management. A staging system, based on the extent of blue-gray discoloration and insensate tissue just after rapid rewarming in conjunction with technetium scanning, has been used to allow earlier prognosis and amputation, if necessary (Cauchy et al. 2001).

Risk Factors

Risk factors for frostbite include factors that increase local heat loss or decrease heat production. Cold, especially windy conditions increase heat loss if clothing and shelter are inadequate. Exhaustion, malnutrition, and dehydration limit heat production. Immobility can limit peripheral circulation. Peripheral vascular disease, Raynaud's disease, diabetes, and smoking cause increased risk due to vasoconstriction. Mental illness and the use of alcohol interfere with appropriate behavioral responses. Body parts that have previously been frostbitten have damaged microcirculation and are at increased risk for recurrent frostbite.

Prevention

Basic measures to prevent frostbite include wearing adequate clothing, including mittens as well as warm socks and boots. (See Table 1) Pay special attention to covering all skin in very cold conditions, while at the same time staying dry, assuring good nutrition, and avoiding dehydration. Goggles and face masks may be needed, especially in windy conditions. Avoid constrictive clothing, especially tight-fitting boots. It is possible to constrict the feet by wearing too many socks or socks that are too thick. For the coldest conditions, insulated double or vapor barrier boots are best. Chemical or electric foot and hand warmers can also be helpful in extreme conditions. Mittens are warmer than gloves.

Some authors recommend prophylactic use of aspirin or ibuprofen, but there is no evidence that this is beneficial. Supplemental oxygen during bivouacs at extreme altitudes (over 7500 m) is likely helpful in preventing frostbite. Application of emollients to the skin is a common practice in many

Table 1. Prevention of Frostbite

Adequate Clothing

- Cover all skin in very cold conditions
- Goggles and face masks
- Avoid constrictive clothing, especially tight-fitting boots
- Do not wear too many socks or socks that are too thick
- In coldest conditions: insulated double or vapor barrier boots

Stay Dry
Good Nutrition
Adequate Hydration
Oxygen at High Altitude
Be Alert for Incipient Frostbite

- Cold or numb fingers or toes
- White appearance of nose or ears

If Early Signs or Symptoms

- Get out of the wind and into shelter if possible
- Remove wet gloves, mittens and socks
- Warm cold extremities
- Replace wet clothing with dry clothing

regions but seems to increase rather than decrease the risk. (Lehmuskallio 2000).

Be alert for incipient frostbite, especially cold or numb fingers or toes or a white appearance of the nose or ears. If any of these occur, get out of the wind and into shelter as promptly as possible. Remove wet gloves or mittens and socks and warm cold extremities that are not yet frozen. In a wilderness situation, the most common method of warming a cold hand or foot is to place it on a companion's abdomen or in the armpit or groin. Replace wet clothing with dry clothing if available (Copass, Nemiroff et al. 2005).

Field Treatment

Before treating frostbite, treat life-threatening conditions such as hypothermia (Copass, Nemiroff et al. 2005) (See Table 2).

Table 2. Treatment of Frostbite

Immediate

- If patient is hypothermic, treat hypothermia first
- Rapid rewarming by immersion in water at 37–39°C if still frozen
- Analgesia as required
- Air dry (not towel dry)

Initial Treatment after Thawing

- Elevate and protect frostbitten extremities
- Fasciotomy if compartment syndrome
- Aspirate or debride clear blisters. Do not open hemorrhagic blisters
- Tetanus prophylaxis
- Aspirin or ibuprofen
- Volume replacement as necessary

Consultation for Use of tPA in Severe Cases

- tPA must be given within 24 hours of rewarming

Disposition

- Superficial frostbite: discharge if patient has adequate housing and has no other indication for admission
- Deep frostbite: admit or transfer

Reduce dislocations if possible and stabilize fractures in anatomic position possible to maintain circulation. Keep the patient warm. Do not rub the affected part directly or with snow. Rewarming frostbitten limbs by a fire or using hot engine exhaust further damages frozen skin (Mills 1993). As discussed in the State of Alaska Cold Injury Guidelines, if transport to medical care will be less than 2 hours, it is preferable not to rewarm frozen extremities (Copass, Nemiroff et al. 2005). During longer evacuations, spontaneous thawing is usually unavoidable, as a result of efforts to keep the patient warm. Do not allow thawed tissue to refreeze. This is critical, because tissue that has thawed and refrozen will no longer be viable. Walking on frostbitten feet causes little additional damage and may be necessary to reach medical care. Once the feet have thawed however, the patient should not walk. Although there is no hard evidence to support the use of aspirin or ibuprofen, either can be given. Some authors believe, on theoretical grounds, that ibuprofen is superior to aspirin (McIntosh, Hamonko et al.). Oxygen is likely to be helpful at high altitude, if it is available.

Rewarming

Once the patient is in a clinic or hospital setting, frostbite that has not already thawed should be treated as soon as possible with rapid rewarming by immersion in water at 37–39°C (Copass, Nemiroff et al. 2005). Older studies used higher temperatures. Water warmer than 39°C does not warm significantly faster but causes more pain during rewarming. A whirlpool is ideal, but any large container can be used. Warm water should be added during rewarming to maintain the temperature of the water. Frozen body parts should not touch the sides of the container. Thawing is complete when the extremity is pliable and is red or purple to the ends of the digits. This usually requires 15–30 minutes. Opiate analgesia may be required for pain relief. Hypothermic patients should be rewarmed to at least 34°C prior to rewarming of frostbite. In order to avoid further skin damage, thawed areas should be air-dried rather than dried with a towel.

Early Care After Rewarming

Injured extremities should be elevated to decrease edema and dressed sterilely or left open to air (Mills 2001). Aloe vera, a thromboxane inhibitor, can be used on frostbitten tissue, although it has not been shown to decrease tissue loss (McCauley, Hing et al. 1983). Swelling may cause compartment syndrome, necessitating fasciotomy (Mills 2001). This is a greater risk after thrombolysis with reperfusion of ischemic tissue. Most clinicians aspirate or debride clear blisters. Debriding hemorrhagic blisters may cause worsening of the injury and is usually avoided (McIntosh, Hamonko et al.). Prophylactic antibiotics are seldom necessary, unless the wounds are clearly contaminated or antibiotics are indicated for coexisting conditions. Tetanus prophylaxis should be given according to usual protocol (Chan and Smedley 1990). Aspirin or ibuprofen is usually started or continued in spite of a lack of evidence supporting efficacy (McIntosh, Hamonko et al.). Based on my experience in Alaska, most patients with frostbite will be volume-depleted and should receive volume replacement with normal saline. Several liters may be required to establish a euvolemic state. As with many aspects of treating frostbite, there does not seem to be any published evidence on this subject. Intravenous fluids should be warmed to 42°C in order to prevent iatrogenic hypothermia.

Patients at risk for amputation of digits, hands, or feet, including partial amputations, who do not have any known contraindications to tPA are candidates for thrombolytic treatment with tPA plus heparin at a center with experience in giving tPA for frostbite, but only if treatment can be started within 24 hours of thawing (Twomey, Peltier et al. 2005; Jenabzadeh, Mohr et al. 2006; Bruen, Ballard et al. 2007). Early consultation with a vascular or burn center is mandatory. Angiography or technetium scanning is used to evaluate the initial injury and guide therapy (Cauchy, Chetaille et al. 2001).

A prospective study of prostacyclin and aspirin with or without tPA showed the better results with prostacyclin alone than with tPA; the authors suggested that addition of tPA might still be beneficial in selected patients (Cauchy, Cheguillaume et al.). If these results are confirmed at other centers, prostacyclin has promise in future care of frostbite.

Many other interventions have been used in the treatment of frostbite, including low molecular weight dextran, vasodilator therapy, hyperbaric oxygen, and surgical or chemical sympathectomy. There is currently insufficient evidence in favor to recommend any of these interventions.

Disposition

Unless they clearly have superficial frostbite, most patients should be hospitalized to determine the extent of injury and for further treatment. Outside consultation or transfer is indicated if the admitting service is not experienced in caring for frostbitten patients. Patients with superficial frostbite can usually be safely discharged if they have a warm place to live and do not require hospital admission for other injuries or conditions. Patients who have had frostbite are more susceptible to frostbite in the future. They should be warned to avoid future exposure to temperatures below −9°C or to take extra precautions if they will be exposed to cold temperatures.

Disclosure Statement

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