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Frostbites in circumpolar areas

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Circumpolar areas are associated with prolonged cold exposure where wind, precipitation, and darkness further aggravate the environmental conditions and the associated risks. Despite the climate warming, cold climatic conditions will prevail in circumpolar areas and contribute to adverse health effects. Frostbite is a freezing injury where localized damage affects the skin and other tissues. It occurs during occupational or leisure-time activities and is common in the general population among men and women of various ages. Industries of the circumpolar areas where frostbite occurs frequently include transportation, mining, oil, and gas industry, construction, agriculture, and military operations. Cold injuries may also occur during leisure-time activities involving substantial cold exposure, such as mountaineering, skiing, and snowmobiling. Accidental situations (occupational, leisure time) often contribute to adverse cooling and cold injuries. Several environmental (temperature, wind, wetness, cold objects, and altitude) and individual (behavior, health, and physiology) predisposing factors are connected with frostbite injuries. Vulnerable populations include those having a chronic disease (cardiovascular, diabetes, and depression), children and the elderly, or homeless people. Frostbite results in sequelae causing different types of discomfort and functional limitations that may persist for years. A frostbite injury is preventable, and hence, unacceptable from a public health perspective. Appropriate cold risk management includes awareness of the adverse effects of cold, individual adjustment of cold exposure and clothing, or in occupational context different organizational and technical measures. In addition, vulnerable population groups need customized information and care for proper prevention of frostbites.

Keywords: *cold*; *frostbite*; *injury*; *circumpolar*; *vulnerable*; *population*

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The circumpolar environments are characterized by considerable fluctuations in temperature and photoperiod with long, cold and dark winters and short cool but bright summers. Winter, as defined by the number of days when the mean daily temperature decreases below 0°C, is the longest season in high-latitude environments lasting for several months depending on the region. The cold environmental conditions in wintertime are often further aggravated by wind and precipitation. Moreover, darkness, snow, and ice further modify the environment and the risks associated with it (1).

Arctic areas are warming as a result of climate change. Different climate changes projections predict a 'polar amplification' where especially winter warming is several fold in the Arctic compared to the global annual mean (2). It is estimated that the increase in mean temperature and precipitation will be combined with an increase in the frequency of very warm and wet winters and summers (2). Despite the warming, cold spells continue to be a problem in northern latitudes, where very low temperatures can be reached in a few hours and extend over long periods. Moreover, the expected increase in wintertime precipitation and changing cryosphere (e.g. retreat of arctic sea ice, earlier breakup of river, and lake ice) can indirectly contribute to human health. Therefore, despite the global warming, cold remains in its various forms (3) and is significantly present in the everyday life of all circumpolar residents. Cold exposure can result in decreased performance, increased morbidity, and mortality and increased rates of injuries causing different types of functional limitations, sick leaves, hospitalization, and in the worst case, death (1, 4, 5). The present article focuses on the occurrence, treatment, and prevention of frostbites occurring in circumpolar areas. The history and research on frostbite are old and several reviews are available (5–13). A few of them are cited here and more can be found in other publications by the authors (14, 15).

Cold exposure

Types of cold exposure

The type of cold that people experience may be exposure to cold air, immersion in water, or through touching (sitting,

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lying, or standing) cold surfaces. Accordingly, cooling is targeted to different areas of the body. Sometimes cooling may also involve specific body regions, such as the respiratory tract. Respiratory tract cooling can be especially pronounced during heavy exercise in cold weather (4). Prolonged exposure to cold, often associated with insufficient clothing or physical activity, may result in whole body cooling and a decrease in core temperature. This type of cooling is further enhanced by exposure to wind or cold water, which increases heat loss from human to the environment. Cooling can also be restricted to the extremities (head, hands, and feet) and is often enhanced by touching or handling cold objects. This type of cooling is common both in occupational and leisure-time activities and pose a significant risk of cold injury.

Occupational and leisure time cold exposure

Cold exposure occurs on average, for short yet repeated periods and includes commuting to work, occupational, and leisure-time exposure. A population study conducted in Finland demonstrated that the average self-reported cold exposure time is approximately 4% of the total time, and most of the cold exposure (71%) was reported to occur during leisure time (16). The degree of exposure to cold is dependent on several factors such as occupation, gender, age, health, physical activity, and education. For indoor workers, cold exposure is probably limited to commuting to work and leisure-time activities.

Although the reported average cold exposure at work among this Finnish population was less than 1 hour per week, cold exposure is substantial in industries such as agriculture, forestry, mining, factory work, construction work and related occupations (16). Cold exposure may also be significant among native northern populations, who are for example reindeer herding, hunting, or fishing. However, the development of vehicles and protective clothing may have to some extent diminished the amount of cold stress (1). One population group that is also exposed to significant cold stress is the military. The duration of outdoor cold exposure in winter during military training can be significant, equaling, or exceeding that of other cold outdoor occupations.

Frostbites

Cold injuries are divided into freezing injuries, nonfreezing injuries, and hypothermia (14, 15). Frostbite is the medical condition where localized damage is caused to skin and other tissues as the result of freezing of the tissue. Frostnip is distinct from frostbite but may precede it. It is a superficial cold injury associated with intense vasoconstriction on exposed skin. However, ice crystals do not form in the tissue, nor does tissue loss occur. Nonfreezing cold injuries often occur as a result of prolonged exposure to temperature above freezing and are associated with wet conditions. The most common nonfreezing cold injuries are trenchfoot and chilblains. Frostbite most commonly occurs in the extremities (hands, feet) and head region (14, 15). However, even genital areas have been reported to be affected by frostbite in Arctic military operations (17).

Frostbite injuries are often classified by the depth of injury and amount of tissue damage based on acute physical findings and advanced imaging following rewarming of the tissue (14, 18). A first-degree injury is characterized by partial skin freezing, erythema, mild edema, lack of blisters, and occasional skin desquamation several days later. Symptoms of stinging and burning, followed by throbbing may be experienced. A second-degree injury is characterized by full-thickness skin freezing, edema, erythema, and formation of clear blisters rich in thromboxane and prostaglandins. The blisters extend to the end of the digit, and usually desquamate and form black hard eschars over several days. Complaints of numbness, followed later by aching and throbbing are common. A third-degree injury is characterized by damage that extends into the reticular dermis and beneath the dermal vascular plexus. Hemorrhagic blisters form and are associated with skin necrosis and a blue-gray discoloration of the skin. The injured extremity may feel like a 'block of wood,' followed later by burning, throbbing, and shooting pains. A fourth-degree injury is characterized by extension into subcutaneous tissues, muscle, bone, and tendon. There is little edema and the skin is mottled, with nonblanching cyanosis, and eventually forms a deep, dry, black, mummified eschar. Vesicles often present late, if at all, and may be small, bloody blebs that do not extend to the digit tips. The patient may complain of a deep, aching joint pain (14).

In addition to the acute injury, frostbite is often associated with different post symptoms, sequelae that include altered vasomotor function, neuropathies, joint articular cartilage changes, and, in children, growth defects caused by epiphyseal plate damage (19, 20). These may cause different forms of discomfort and functional limitations that can persist for several years.

Pathophysiology of frostbite

The pathophysiology of frostbite is described in detail previously (14, 18). It can be divided into four overlapping pathologic phases: prefreeze, freeze–thaw, vascular stasis, and a later ischemic phase (18). The prefreeze state is characterized by a considerable decrease in blood flow as a result of skin cooling and vasoconstriction. However, this phase does not involve the formation of actual ice crystals. In the freeze–thaw phase, ice crystals form intra or extracellularly causing protein and lipid derangement, cellular shifts of electrolytes, and dehydration as well as cell membrance lysis and death. The thawing process may initiate ischemia-reperfusion injury and the inflammatory response. In the vascular stasis

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phase, vessels constrict and dilate or blood may leak from vessels. The later phase of a frostbite injury is characterized by tissue ischemia and infarction due to an inflammation response, intermittent constriction of arterioles and venules, and a continued reperfusion injury (18). The necrosis of tissue following frostbite is due to either cellular injury or secondary to a vascular lesion (14).

Occurrence of frostbites in circumpolar areas

The occurrence of frostbite in different populations has been previously described (7, 8, 13). Frostbite occurs commonly in the general population among men and women of various ages (21–23). For example, in Finland the proportion of annually occurring mild frostbite was 13% (330/2550) and severe frostbite 1% (95/8788) (13). Of note, these injuries are commonly observed already among adolescents (23).

Occupational

The circumpolar environment itself is a hazardous work setting, with special risks posed by great distances, permafrost, cold waters, high wind speeds, ice, blizzards, and darkness. The abovementioned features contribute to higher occupational risks of frostbite compared with other areas (24). Summaries of the occurrence of occupational cold injuries have been previously reported (4, 14, 21). A study analyzing cold injuries using workers' compensation claims in the United States reported highest rates of injury occurring in agriculture, oil and gas extraction, trucking and warehousing, protective services, and interurban transportation. Vehicle breakdown or contact with water, gasoline, alcohol, or cold water were noted as contributing factors on many of the compensation claims (25). In a Finnish study, frostbites were reported in occupational groups such as skilled agricultural and fishery workers, craft and related trade workers, plant and machine operators, assemblers and technicians and associate professionals. Work-related risk factors included employment in certain industries, high physical strain, and high reported weekly cold exposure at work (21).

A specific occupational group at high risk for frostbite is reindeer herders, where the annual incidence of frostbites was 22% (26). The amount of snowmobile driving, area of operation, and white finger symptoms were related to an increased risk of frostbite. Furthermore, vibration white finger syndrome associated with snowmobile use further increased the risk of frostbite in reindeer herders (26).

Frostbites are also reported commonly during military training and operations (27–31). The Finnish Defense Forces documented an annual incidence of frostbite of 0.4% between 1976 and 1989 (30). In Alaska, the annual occurrence of medically investigated frostbite among soldiers ranged from 0.2% to 1.2% between 1990 and 1995 (27). Arctic military operations in Norway resulted in several frostbites, and the observed individual differences in the cold-induced vasodilatation response could explain individual susceptibility to cold injuries (31). Reports indicate that the incidence of cold weather injuries among US military personnel decreased from 38.2/100,000 in 1985 to 0.2/100,000 in 1999. Reasons for this decline are multifactorial (29).

Although there are no scientific reports, one could also assume that frostbite injuries occur in the oil and gas industry, fishing industry, tourism, transportation, and forestry which involve special occupational risks related to the circumpolar environment (24).

Leisure time

As most of the cold exposure occurs during leisure time, it is likely that frostbites are associated with different outdoor activities. A population study showed a relatively high incidence of frostbite among students, pensioners, and the unemployed, which may be related to long times spent in the cold during the leisure time in these groups (16, 21). Also, the occurrence of frostbite among office workers suggests that these had occurred during the leisure time.

Significant cold exposure during leisure time occurs in different outdoor sports activities such as among joggers, during Alpine and Nordic skiing, mountaineering, cold-weather distance running and cycling, speed skating, and luge, or while playing outdoor team sports (32). Cold injuries are common in mountaineering (33, 34). Epidemiological evidence indicates that frostbite risk is clearly increased above 5,182 m (33). Also recreational or occupational use of snowmobiles is associated with frostbites (26, 35).

Frostbite is a common theme in historical descriptions of arctic explorers (3, 36–38). There are several reports of cold injuries (frostbite, trenchfoot) during Arctic expeditions or ski treks (36, 39, 40). These expeditions involve several stressors in addition to the cold environment (cold temperatures, wind, and snowfall) including for example fatigue, nutritional deficits, dehydration, hormonal changes, and psychological stressors. More recent studies have examined the occurrence of cold injuries among personnel overwintering in Antarctica where the occurrence of frostbites was 65.6 per 1,000 per year (41). The increasing tourism to the Polar regions may also involve risk of frostbites injuries (42).

Risk factors of frostbites

Several environmental and individual risk factors increase the risk of frostbites (Table 1) and these are described in more detail underneath.

Table 1. Factors predisposing to frostbite

Environmental
Temperature
Wind
Wetness
Contact with cold objects or liquids (e.g. petroleum, oil, and lubricants)
Duration of cold exposure
Geographical area
Hypoxia
Altitude
Individual
Physical/anthropometric
Age
Gender
Race
Behavioral
Cold acclimatization
Alcohol use
Fatigue
Dehydration
Smoking
Use of protective ointments
Inappropriate/wet clothing
Constrictive clothing (e.g. tight boots)
Prolonged stationary posture
Health related/physiological
Raynaud's phenomenon
Vibration-induced white finger
Cold induced vasodilation reactivity
Other peripheral vascular diseases
Diabetes
Peripheral neuropathies
Medication (e.g. vasoconstrictive drugs)
Previous cold injury
Psychiatric disorder or altered mental status

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Environmental-risk factors

The incidence of frostbite is related to the intensity and duration of cold exposure. Exposure times for injury vary from minutes to several days depending on the magnitude of exposure, degree of protective clothing, and physical activity level. According to experimental research, the risk of frostbite on the bare skin is minor at environmental temperature above –10°C (43). The latitude of residence (i.e. the annual number of cold days) as well as the length of the daily cold exposure affect frostbite risk (23). It also seems that people living in urban areas are at higher risk of frostbite, and possibly related to inexperience and inappropriate protection (44). Wind markedly increases the cooling rate by increasing convective heat loss and reducing the insulation value of clothing, thus increasing the risk of frostbite. The windchill temperature (WCT) provides the relative risk for frostbite occurring on the bare skin and predicted time for freezing risk at given air temperatures and wind speeds (45). Currently, the threshold predicting frostbite risk is being discussed, including pain and numbness thresholds predicting adverse cooling (46). The risk of frostbite is less than 5% when the ambient temperature is above –15°C, but increased surveillance is warranted when the WCT falls below –27°C (47). In addition to ambient temperature and wind, merely touching cold materials (e.g. metal) is a risk factor for frostbite. The degree of cooling while touching cold materials is dependent on the surface temperature, type of material, duration of contact, and several individual factors. Safe limits values for gripping or touching cold objects have been developed (48, 49). As an example, frostbite can develop within 2–3 seconds when touching metal surfaces that are at or below –15°C (49). Other factors that increase heat loss and cooling rate and increase the risk of frostbite are wetting the skin. Also, case studies have demonstrated frostbites or 'cold burns' when handling cooled liquids such as liquid oxygen (50) or liquid petroleum while refuelling car (51) or from contact with butane or propane canister (52). Finally, high altitudes and hypoxia increase frostbite risk (33, 34).

Individual factors

Several individual factors related to physical features, behavior, and health affect the risk of frostbites (Table 1). A recent population study demonstrated that health-related factors such as diabetes, white fingers in the cold, cardiac insufficiency, angina pectoris, stroke as well as depressive feelings increase the risk of frostbite (21). In addition, certain disease states, such as peripheral vascular disease, atherosclerosis, arteritis, Raynaud's phenomena, vibration-induced white finger (VIWF), hypovolemia, diabetes, vascular injury secondary to trauma or infection, and previous cold-related injuries, may predispose to cold-related injury (22, 30, 33, 53). Psychiatric disorders are commonly detected among frostbite patients (14, 53). Any immobilizing injury for example impairing the distal circulation predisposes persons to frostbite (53). Although there are no scientific reports available, certain age groups that are susceptible to cooling, may also be at higher risk to receive a cold injury. Children have larger surface-to-mass ratio compared with adults, and lesser possibility for producing heat, which explains the lower thermoregulatory capacity in the cold and higher risk of cold injuries. Also, the elderly people have a lowered heat production capacity (diminished muscle mass) as well as weakened ability to

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sense cold (54, 55). Furthermore, elderly persons have commonly one or more chronic diseases or use medication that may affect their thermoregulation in cold. Overall medications such as β blockers, sedatives, and neuroleptics may affect thermoregulation and increase the risk of frostbite (53). Health care personnel should recognize these health conditions and provide appropriate advice and treatment to prevent frostbite from occurring.

Several behavioral factors influence the risk of cold-related injuries. Alcohol consumption and smoking increase the occurrence of frostbite (21, 22, 33). The previously mentioned psychiatric disorders increase unsafe behavior and frostbite risk (53). Inappropriate clothing (e.g. lack of gloves, headgear,scarf, or wet clothes) and/or constrictive clothing, and prolonged stationary posture increase the incidence of frostbites. Interestingly, the use of protective ointments is associated with an increased risk of frostbite of the head and face (30). Among military personnel, lower level of education/training or military rank, as well as situational misjudgments, accidental situations, fatigue, and insufficient nutrition are associated with a higher incidence of frostbite. US Military studies suggest that African-American soldiers and those from warmer climatic regions are more susceptible to frostbite (29). The association between cold acclimatization and frostbite is unclear. The blunted vasoconstriction of for example hands due to repeated exposures to cold may improve manual dexterity, but at the same time increase cooling and put the hands at greater risk for cold injuries (56).

It should be noted that considerable amount of frostbitten persons suffer from different post symptoms as a result of their injury. The most typical sequelae are hypersensitivity to cold, pain, and ongoing numbness and may cause functional limitations persisting for several years (14, 15, 53).

First aid and treatment

The treatment of frostbite has been described in detail previously (15, 18, 53, 57) and is distinguished to first aid in the field as well as medical therapy provided in a hospital. Initial field management of frostbite includes prevention of further cold injury, hypothermia, and dehydration. The patient should be covered, protected against wind, and any wet and constrictive clothing should be removed and replaced with dry ones. Heating of the frozen area should be avoided. Thawing should be deferred until the risk of refreezing is eliminated. The risk of refreezing and causing even more severe damage is a real concern. Frozen extremities should be immobilized, elevated, and handled gently. ‘Home remedies’ such as rubbing snow on frostbitten tissue increase tissue damage (15, 18, 53).

Arctic indigenous populations have long-term experience with cold injury prevention and treatment. Fortuine (36) described experiences from the Arctic exploration of Edward Parry in 1821–1823 where Inuit prevented cold injuries by warming their hands against their body, rather than rubbing the extremities with snow that has been a common misbelief. The indigenous populations have also applied their own treatment against frostbite such as topical applications of nasal secretions, seal oil, and whale blubber (58). A case report even describes that urine help preventing the development of a contact frostbite (59).

The details of frostbite care have been described in several publications (15, 53) and are not discussed in detail in this article. In summary, the core hospital treatment of frostbite includes rapid rewarming of the injured area in warm water, gentle early conservative treatment (leave most blisters intact, no early surgery, or amputations), meticulous local care, adequate pain relief, and physical therapy.

Prevention

Increasing awareness

The prevention of local cold injuries includes increasing public awareness of the adverse effects of cold exposure, attention to related potential risks, and implementing risk management and prevention strategies. For this purpose, advice for the public related to preventing adverse cold effects is being prepared by the WHO and will be published shortly. The special needs of susceptible population groups who may not be able to adequately care for themselves, such as the elderly, the very young, socially or economically deprived people, and those with mental impairments, should be taken into account when providing individual recommendations. Also, people suffering from chronic diseases may be at higher risk to receive frostbite. Individuals must be educated to recognize warning signals such as sensations of cold, pain, and numbness and to prevent further cooling by protective clothing or by seeking shelter. Special training and education about injury prevention must be provided to persons who work or spend recreational time in cold conditions. Efficient behavioral means for preventing frostbites from occurring include careful planning of activities (and taking into account the expected environmental conditions), maintaining adequate nutrition and hydration, and avoiding alcohol. Cold protective clothing is necessary for maintaining a thermal balance and for slowing or preventing adverse cooling. Some principles for appropriate clothing are discussed underneath.

Clothing

Multilayer clothing should be used and adjusted according to the prevailing environmental conditions (temperature, wind, precipitation) as well as the physical activity level. Sweating should be avoided in cold conditions, as this increases heat loss when the physical activity level is suddenly lowered. Clothing should be dry and noncompressing and wet clothes should be changed to dry ones as soon as possible. Headgear should be adjustable to cover maximal areas of the head. If necessary, a face mask can be used. The face can also be protected by a wide hood that leaves the face uncovered, but provides protection. Mittens provide better hand protection than gloves. The smaller surface area of mittens combined with the presence of air and all fingers together in one compartment decreases heat loss. Thin inner gloves may be used if manual dexterity during contact with metal objects is required. Shoes, boots, and socks should be dry and sufficiently loose (15).

Occupational management of cold injuries

Advice on the appropriate occupational cold risk management is provided in an international standard (60). Cold risk management at workplaces includes organizational and technical measures. Metal tools and instruments can be coated which is an efficient method for reducing conductive cooling and frostbite risk. Insulation may also be added to the specific site of garment contact, e.g. to the palm side of the glove. Additionally, external heating sources can be used to warm the work or recreational environment. Organizational injury prevention consists of appropriate advance planning of activities, adjusting scheduling to expected weather conditions based, and knowing where safe and warm shelters exist.

Conclusions

Global warming and the changing climate are likely to bring not only warmer average temperatures, but possibly also a greater frequency of extreme weather events, changing ice covers, and increased amounts of precipitation which contribute either indirectly or directly to human health. Therefore, the need for appropriate cold risk management to prevent cold injuries is emphasized. The populations that are at the greatest risk for frostbites are the children, elderly, homeless people, or persons suffering from chronic diseases. Ageing populations, urbanization and the variable housing and socioeconomic conditions are all factors that contribute to cold-induced health problems in circumpolar regions.

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