Prediction and Prevention of Frostbite

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ABSTRACT

Occurrence of frostbite: *Among teenagers, the annual incidence of frostbite in Finland was 4.1% in boys and 2.4% in girls. Lifetime experience of frostbite was 44 % among men entering their military service. In Finland during the 6 to 12 month military service the prevalence of frostbite was 1.9 % and sequelae of hand frostbite were present in 63 %.* ***Prediction of frostbite:*** *Individual risk factors of frostbite (95 % CI) are Raynaud's phenomenon, (OR 1.66 – 3.87), hand vibration (OR 1.07 - 4.03) and current smoking (OR 1.02 – 3.15). Development of frostbite is associated with fatigue, low physical activity, dehydration and use of alcohol.During military service independent risk factors for developing face and ear frostbite were the following: not wearing a hat with earflaps or a scarf, applying protective ointment, and travelling in an open vehicle.* ***Prevention of frostbites:*** *Screening before military service by e.g. a questionnaire assessing Raynaud's phenomenon, hand vibration and current smoking enables to identify personnel that are susceptible to frostbites. These persons may be either excluded from field operations, or be given special training on how to protect themselves. Education of officers and physicians is essential in order to be able to plan and train for winter manoeuvres.* ***Protection from frostbites:*** *Each individual should be aware of the early signs indicating an increased risk of frostbite and know how to protect themselves. Appropriate selection and use of winter clothing protects from frostbites. Wind-proof, dry and not too tight clothing should be preferred. Exercise leading to exhaustion should be avoided. During periods of inactivity, the metabolic heat production should be increased by muscular work if possible, or alternatively use additional clothing or seek shelter. Adequate nutrition and hydration protects against frostbites. It is not recommended to use ointments or wash the face with strong detergents prior to the cold exposure. Smoking should be avoided, as it increases the risk of developing frostbite. Frostbites related to contact cooling may be prevented by coating metal surfaces or using contact gloves.*

1.0 INTRODUCTION

It is important to recognise cold weather injuries (CI) in military operations and especially in military health care. Frostbite, trench foot and hypothermia have been a common problem in warfare in different modern conflicts and in various armies [1]. Among Israeli soldiers, peripheral injuries accounted for 55 % and hypothermia for 45 % of all CIs [2]. In Finland in peacetime land operations frostbite contributes to the majority of these injuries in Finland. Trench foot injuries related to poor hygiene are completely missing from the Finnish registers. However, non-freezing cold injuries, causing temporary peripheral neuropathy, are possible also in peace-time military winter training [3] The risk of such temporary non-freezing cold injuries should also be recognised.

Contact with metal or other materials of high conductance are nowadays a remarkable cause of military-related frostbites in Finland [4]. There is evidence that individuals do not recognise the high risk of frostbite related to contact with cold materials and lack the experience of how to properly manage this situation.

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Frostbites requiring hospitalisation are often associated with long treatment periods and are both demanding and costly. The majority of frostbites result in various long-lasting post-symptoms, causing commonly limitations in performance [5].

2.0 OCCURRENCE OF FROSTBITES

The occurrence of frostbites in civilian life has previously been mainly reported from referral or tertiary care hospitals [6] demonstrating very low frequencies: 0.001 - 0.0016 % [7, 8]. In the Finnish hospital register, covering all types of hospitals, the incidence rate was 0.0025 %. The annual incidence for having a frostbite increased markedly by increasing age and was very low in women (Fig 1) [9].

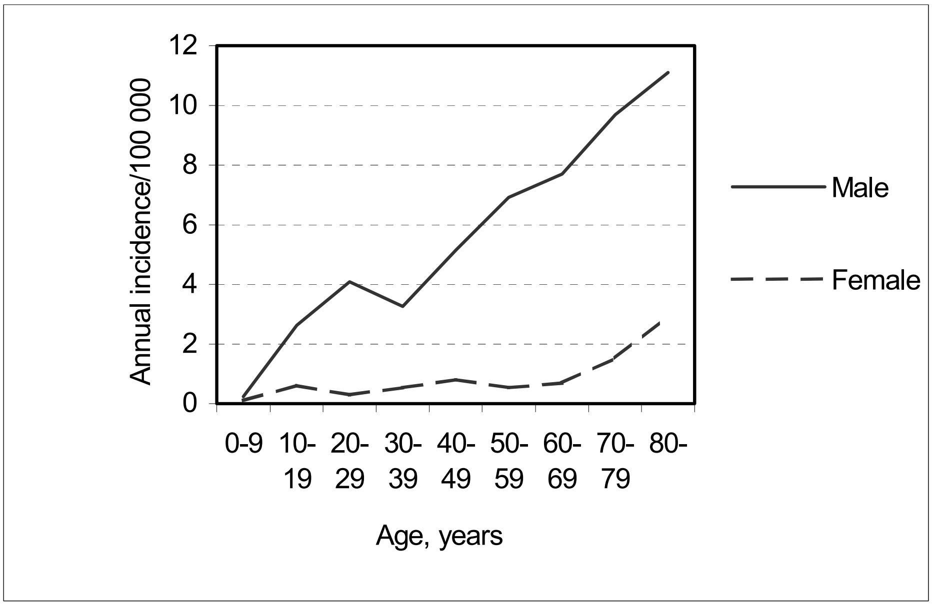

Figure 1: Average annual incidence of frostbite per 100 000 inhabitants by age and sex (Juopperi et al. 2002). Permission to reproduce illustration from Int J Circumpolar Health.

The annual occurrence of self-reported, at least blister-grade frostbites in 25 to 74 year-old Finns in 2002 was on average 0.9 %, being 1.4 % for men and 0.4 % for women. In this population the majority (90 %) of the frostbitten persons reported more than one frostbite in the year of reporting [10]. Of teenagers aged between 14-18 years in northern Finland, 4.1 % of the boys and 2.4 % of the girls reported having received a frostbite of at least blister-grade or worse during the year [11]. Young men entering their military service (mean age 21 years) reported in 44 % of the cases having received at least one frostbite in their life. Out of the total 2555 respondents who had reported developing a frostbite during their lifetime, 21 % had experienced this once, 52% had experienced it between two to five times, and 37 % had experienced frostbites more than five times [12] (Table 1). The occurrence of frostbite in civilian life is strongly dependent on the latitude of the place of residence [9] as well as the individual's occupation [10].

In 1976-89, the annual incidence of frostbite in the Finnish Defence Forces (n=2074) was 0.4 % [13]. In the Finnish northern Command during the winter 1995-96 the occurrence of frostbite was 2.3 %, also including self-reported mild first-degree frostbites [4]. In Alaska in 1990-95, the annual occurrence of medically investigated frostbites varied from 1.2 % to 0.2 % [14]. There has been a strong reduction in US military cold weather injuries, from 38.2/100,000 in 1985 to 0.2/100 000 in 1999; 43.8 % of all their cases were frostbite [1].

Among Finnish soldiers (1976-1989) the location of frostbites was most often in the head region (44 % of all frostbites) [15]. However, in the Finnish northern command in 1995-96 the hands were most frequently frostbitten (61.5 %), followed by the head region (28.5 %), and lastly the feet (10 %) [4]. In Alaska (1990-95) frostbites occurred in the head region in 39.1 % of the cases, in hands in 27.9 % of the cases, and in the feet in 24.9% of the cases [14]. In the US military in 1980-99 the most common site for the occurrence of frostbite was feet, followed by hands and the head region [1]. Self-reported lifetime occurrence of frostbite in Finnish men entering military service demonstrated that the relative occurrence for development of frostbite was 31 % for the head, 20 % for the hands and 15 % for the feet [12]. The frostbites were most often mild (frostnips, 1st degree superficial). Only 12 % of all frostbites were more severe, i.e. causing post-symptoms (Table 1).

Table 1: Life-time cumulative occurrence of frostbite in different areas of the body in Finnish men entering their military service (n=5839). Values denote absolute (percentages in parenthesis) numbers of subjects. Data items designated as missing represent subjects whose answers on frostbite were incomplete.

Degree of frostbite	Number of frostbites			
	All	Head	Hands	Feet
All	2555 (44 %)	1668 (31 %)	1154 (20 %)	810 (15 %)
missing	12	418	33	393
1st degree, superficial	2333 (41 %)	1462 (28 %)	1064 (19 %)	738 (14 %)
missing	83	590	179	591
>1st degree, deep	671 (12 %)	459 (9 %)	213 (4 %)	174 (3 %)
missing	40	823	79	641

(Ervasti et al. 2004). Permission to reproduce table from Int J Circumpolar Health.

Among civilians treated in hospitals in Finland, frostbite affected the feet in 61 %, the hands in 34 % and the face in 5 % of all the cases. These injuries were mainly severe [9].

Different post-symptoms, sequelae, are commonly present after blister-grade or more severe hand frostbite [5,16,17]. For example 65 % of the soldiers having received a frostbite during military winter manoeuvres had post-symptoms after a 6-month follow-up [16]. Similarly, 63 % of Finnish conscripts reported suffering from at least one post-symptom related to a frostbite [5]. In Norwegian soldiers they are commonly seen even after mild first-grade frostbites [17]. The most typical symptoms are hypersensitivity to cold, pain, numbness, and changes in sensory functions (Table 2) [5]. Also clinical findings such as arthritis, bone deformations, scars, skin and nail dystrophia etc. are observed in association with more severe frostbites [6]. It is important to recognise that the sequelae related to frostbite injuries may result in decreased performance and a long term disability of the individual [16]. According to an interview, 13 % of the persons suffering from post-symptoms related to frostbites reported having suffered from temporarily decreased motivation or functional abilities in cold work [5].

Table 2: The sequelae of the frostbitten area in conscripts (n=131) assessed by a questionnaire and interview.

Sequelae	Questionnaire (n=131) n (%)	Interview (n=30) n (%)
Sensitivity to cold	48 (37 %)	16 (53 %)
Numbness of fingers	10 (8 %)	12 (40 %)
Decreased tact. sens.	5 (4 %)	10 (33 %)
Hyperhidrosis	3 (2 %)	6 (20 %)
Raynaud's phenomenon	1 (1 %)	6 (20 %)
Superficial pain	-	5 (17 %)
Athropic ulcer	1 (1 %)	-
At least one sequelae	69 (53 %)	19 (63 %)

(Ervasti et al. 2000). Permission to reproduce table from the Int J Circumpolar Health.

3.0 PREDICTION OF FROSTBITES

An experiment conducted in a cold climatic chamber with winter-clothed sitting volunteers demonstrated that frostbites occurred in bare fingers at or below -10 °C temperature [18]. The risk of finger frostbite increases linearly from 5 to 95 % when temperature at the skin surface decreases from -4.8 °C to -7.8 °C [19]. The highest reported ambient temperatures causing frostbites in a study population consisting of hospitalised patients was between -6 to -10 °C [9]. In measurements carried out during typical tasks of infantry and artillery training at 0- -29 °C, 20-69 % (at different ambient temperature ranges) of finger temperatures were low enough to cause cold thermal sensations. Sensation of cold was experienced on the average at finger temperature of 11.6 °C [20].

When examining the relationship between ambient temperature and the occurrence of frostbites in Finnish hospitalised persons, it was observed that frostbite began to appear in the temperature range between -6 °C to -10 °C, increasing strongly between -16 °C to -20 °C, and furthermore with even colder ambient temperatures [9].The occurrence of military frostbites in Alaska increased strongly when the WCI temperature was at or below -18 °C [14]. Wind is a marked factor increasing the risk of frostbite in cold environmental conditions. The new wind-chill index calculates wind speed at an average height of 1.5 m (typical height of an adult human face) based on readings from the height of 10 m (typical height of an anemometer). If the local wind velocity at the ground level is actually measured, it must be multiplied by 1.5 before inserting the value into the wind-chill equation [21].

Wet clothing and skin increases the risk of frostbite because of decreased insulation of clothing and possibly increased evaporative heat loss. An urban lifestyle increased the risk for receiving frostbite in Helsinki more than in other parts of Finland [9]. In civilian activities the development of frostbite is associated with fatigue, low physical activity, dehydration and use of alcohol [22]. Moreover, also sicknesses decreasing physical performance or causing inadequate behaviour increase the risk. During military service independent risk factors for developing frostbite were: not wearing a hat with earflaps or a scarf, applying oily protective ointments, and travelling in an open vehicle [15]. The individual risk factors of frostbite (95 % CI) are Raynaud's phenomenon, i.e. periodical attacks of white fingers (OR 1.66 – 3.87), hand vibration (1.07 – 4.03) and current smoking (1.02 – 3.15) [12].

Raynaud's phenomenon is commonly associated with frostbites as being its post symptom. However, it is also most probably an individual risk factor for receiving frostbite [5].

4.0 PREVENTION OF FROSTBITES

It has been demonstrated that frostbite occurs repeatedly in certain individuals [10,12,23]. Poor physical fitness, lack of cold adaptation and health problems decrease the possibilities to cope with cold. In military service conducted in cold regions, selecting personnel beforehand by questionnaires and health screening is easy [24]. This screening helps to either exclude from field operations persons who have an increased individual risk for receiving a frostbite, or alternatively makes it possible to offer them special training to protect themselves against frostbites. Education aimed at unit commanders, physicians and all soldiers is frequently used in different armies. Proper training and giving individual responsibility to unit commanders to prevent frostbite are well-known effective prevention tools confirmed by US, British and Finnish experience [1,4].

Today, Finnish military recruits have much lower physical fitness than before. Thus, improving the physical fitness at the beginning of their military service helps to reduce the risk of fatigue, and consequently the risk of frostbites as well. Unit commanders are today aware of the fitness classes of their soldiers. In addition, the physical load of different military training manoeuvres in different environments is also known. By combining this knowledge it is possible to plan the training so that possible exhaustion can be predicted and the related increased frostbite risk can be prevented.

The risk for frostbite is increased by fatigue [14] and possible loss of vigilance. Tasks carried out in severe cold conditions should therefore be done in pairs in order to assure that nobody gets exhausted or loses his/her vigilance. The pairs should also observe each other's faces to detect early signs of frostbite. Own sensation of cold or pain should be carefully taken into consideration. Cold pain and numbness are important warning signals. Numb skin denotes that skin temperature is below 7 °C, and there is no longer any sensation to give warning of tissue freezing. Warming of the numb body part should be carried out immediately.

In general, modern military winter clothing gives good protection against cold. A valuable preventive tool is to advise how to combine the different parts of multi-layer field clothing, taking into account environmental conditions as well as the physical load of training. At whole-body level, the prevention starts with the recognition of the risks and the threshold limit values. Based on that, appropriate clothing should be selected. For determining the required clothing insulation, the IREQ calculation [25] as well as earlier experiences can be used. It is important to wear enough clothing, but not too much, so as to avoid sweating. Clothing should be dry and non-compressing. Wet clothes should be dried or changed to dry ones as soon as possible. If cold exposure is expected to last for several hours, or the conditions are expected to change during the exposure, spare clothing should also be brought along.

Inactivity always increases the risk of frostbite in cold winter environments. Easily wearable additional clothing ("pause clothing") and muscular activity are efficient methods to maintain heat balance during the pauses. The rewarming exercise should be intensive enough to increase heat production, but not too intensive to stimulate sweating.

Good nutrition, including good fluid balance, is required. However, the nutrition should not include a marked amount of alcohol. Smoking causes peripheral vasoconstriction and should therefore be avoided [26].

5.0 PROTECTION AGAINST FROSTBITE

Head Protection

For the cold protection of the head, the headgear should be well adjustable. In severe cold exposure the headgear should cover maximal areas of the head. If necessary, a face mask can also be used.

Even a thin face mask makes it possible to work at temperatures 10 – 20 °C lower than without the mask [27].

The face can also be protected by a wide hood that leaves the face uncovered but provides a calm shelter for the face and other parts of the head as well. A hood, reaching maximally 5 cm in front of the face, gives good protection and decreases heat loss from the cheek by about 30% [28]. The beneficial effect of the hood would naturally be greater if the wind were coming from the side or the back.

Emollients do not provide any protection against frostbite. Instead, they may increase the risk of frostbite or give a false estimation of improved cold tolerance [15,29,30,31].

Hand Protection

For hand protection mittens are better than gloves, because the surface area is smaller, mittens contain a lot of air and the fingers are together, thus minimising heat loss. Even partial protection (e.g. fingerless gloves) is better than bare hands. If metal objects are handled and good manual dexterity is required, thin inner gloves, which can be used without mittens, prevent contact cooling efficiently. Because good circulation in the fingers is necessary in order to maintain a high temperature, whole-body thermal balance should be kept at a thermoneutral level.

To prevent conductive cooling, thermal insulation should be increased in contact areas. Insulation could be added either to the object (e.g. the tool) itself, or to the specific site of garment, e.g. to the palm side of the glove. Even a minimal cover, such as 0.25 mm polyethylene coating of metal, decreases the cooling rate markedly [32].

Leg and Feet Protection

For the maintenance of high leg temperature, shoes/boots should be dry and sufficiently loose. The legs should also be dry. Socks should be changed as often as they get wet. Tight socks should be avoided. Keeping up good circulation by thermoneutral whole-body heat balance is equally important for the legs as for the arms and hands.

In long-term exposures to cold, the maintenance of high toe temperature is one of the most difficult tasks. Toes are easily cooled, but their rewarming is difficult. If an external heat source is not available, the best rewarming method is walking, which produces heat efficiently, and leg blood flow is at the same time increased by the rhythmic contractions of the leg muscles [33].

6.0 CONCLUSIONS

Frostbite is common in civilian life at northern latitudes, especially among teenagers, and with increasing frequencies in the north. The incidence rates of more severe frostbites increase with age, and especially in males. In military actions frostbite is the most important cold weather injury. Its main occurrence can be observed at temperatures at or below -18 °C. Mild frostbites are most often located in the head region and the more severe ones in the feet. It is common that the same individual may receive a frostbite repeatedly. Individual risk factors to frostbite are Raynaud's phenomenon, hand vibration exposure and current smoking. Situations where individuals are at higher risk for receiving frostbite are exhaustion and fatigue, low activity, dehydration and while wearing incorrect or wet clothing. The prevention of frostbites is possible by excluding from cold field operations such individuals who are at the highest risk to develop frostbite or alternatively providing them training on how to protect themselves. Appropriate multi-layer clothing and its correct combinations provide good tools for soldiers and their responsible unit commanders enabling them to perform their duties in cold environments. To prevent frostbites, it is necessary to recognise the individual-, environment- and behaviour-related cold risks, practice the tasks in cold, eat and drink well, do physical exercise and take care of one's fellow companions. If some parts of the body become numb, they should be warmed immediately and further cooling should be avoided. In cold environmental conditions it is not advisable to get fatigued to exhaustion, sweat excessively, use tight and/or wet clothing, drink alcohol, smoke and expose oneself unnecessarily to wind, cold metals or fluids. Many of these risk factors have already been recognised, and proper management has been adopted during the past few years in military operations. This has resulted in reports demonstrating a strongly decreased occurrence of frostbite in soldier epidemiology.

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