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Frostbite incidence is a selective term and dependable on methodology — a narrative review

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Review

Abstract

Introduction: Frostbite is freezing of the tissue that mostly affects skin but also the underlying tissues. It results from prolonged exposure to temperatures below the freezing point of water (0°C). One of the many consequences of climate change is extreme cold events, which increase the risk of frostbite in the general population, particularly among individuals who are involuntarily exposed to cold for prolonged periods of time. Although frostbite has been a known phenomenon for a long time, occurring as early as 5000 years ago, the exact incidence of frostbite is not known. This is partly due to variable internal (frostbite susceptibility, hydration status, protective garments) and external etiological factors (wind chill, precipitation, altitude), that never coincide all at the same time.

Objectives: The objective was to compare the incidence rates of frostbite in the published studies that focused on frostbite incidence.

Methods: Out of a total of 61 studies using the keywords "frostbite" and "incidence" on PubMed, we selected seven that dealt with frostbite incidence over 20 years. We briefly summarized and compared the results of the studies.

Results: The comparison of the seven studies shows a great variability of frostbite incidence depending on the population, its size, and the method of data collection. Studies that included civilian populations have significantly lower frostbite incidence rates than studies focusing on individuals who are exposed to temperatures below 0°C for extended periods, such as mountaineers, military personnel, workers in cold storage houses or homeless people. The results highlight different incidence rates for different populations and indicate that retrospectively collected data are insufficiently comparable among studies. Frostbite incidence, expressed as the ratio of injured individuals to non-injured inhabitants, is only comparable in studies using the same

Keywords

- frostbite
- incidence
- exposure to low temperatures

Contribution

A – Preparation of the research project
B – Assembly of data
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

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methodology. Enhanced frostbite susceptibility is a confirmed fact and was generally not considered in most of the studies.

Conclusions: Frostbite incidences of the included studies are insufficiently comparable to draw any conclusions on possible general frostbite incidence in a population. To enhance our ability to estimate or predict frostbite occurrences within the general population, establishing an international or national frostbite registry in high-risk countries could be helpful.

Introduction

Frostbite is a condition that mostly affects skin but can also affect underlying tissues. It results from prolonged exposure to temperatures below the freezing point (0°C for water and −0,55°C for tissue.[1] It can range in severity from superficial frostbite (affecting only the superficial layers of the skin), to deep (severe) frostbite that also affects muscles, tendons, and bones. In cases of deep frostbite, damaged tissue must be removed and digit amputations may be necessary).[2]

Frostbite has been observed for many centuries. The first occurrence of cold-induced injury was identified in a pre-Columbian mummy dating back approximately 5000 years. Hannibal's soldiers also experienced frostbite during their crossing of the Pyrenees, losing about half of his 46,000-strong army. Nearly all of the 250,000 soldiers who participated in Napoleon's invasion of Russia in the winter of 1812–1813 suffered from frostbite, resulting in only 350 able-bodied soldiers returning six months later.[3] Today, there are numerous studies examining frostbite among military personnel.[4,5] Interest in frostbite and its causes among civilians, as well as possible preventive measures, has expanded in recent years. This could be due to increased extreme weather events with very cold temperatures as a result of current climate change, leading to more frequent occurrences of frostbite.[6,7] Individuals who are involuntarily exposed to cold, such as homeless people or those who work outside during extreme cold, are particularly at risk for frostbite.[5,8,9,10] Severe frostbite can lead to complications such as enhanced cold sensitivity, persistent numbness, amputations, or death.[5] The biggest issue with the studies concerning frostbite incidence so far is the variable methodology, which is due to the fact that the published articles are mostly retrospective in nature, dealing with a specific population in a particular environment. Comprehensive studies, describing the incidence of frostbite precisely, are currently lacking.

The purpose of this review is to provide an overview of some of the data collected thus far regarding frostbite to illustrate the extent of frostbite within a larger population and to demonstrate data variability. One of the goals of analyzing frostbite incidence is better understanding its occurrence in general population and prevent it in the future as far as possible.

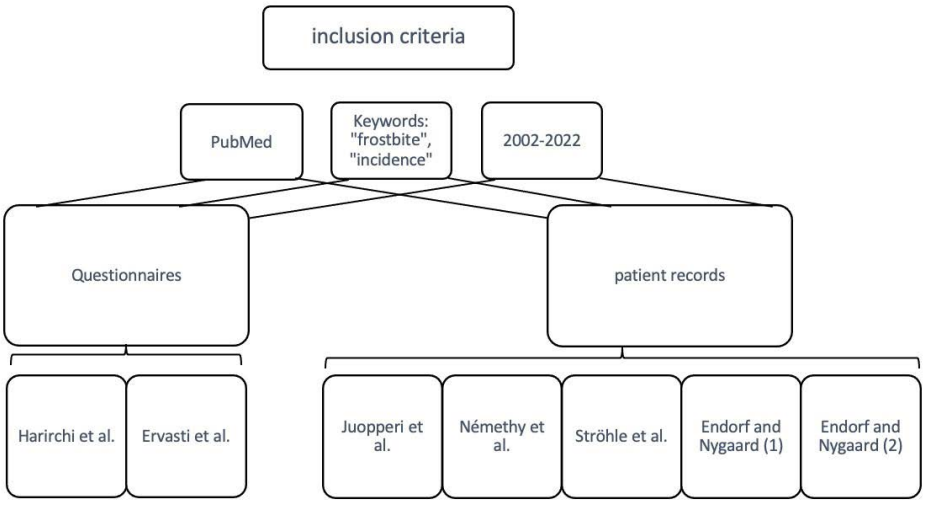

Figure 1. Methods for data collection

Methods

To conduct a review on the incidence of frostbite, we searched for articles using the keywords "frostbite" and "incidence" on PubMed for the period between 2002 and 2022 (a duration of 20 years). We selected seven out of a total of 61 studies, which met the criterion of providing an estimation of incidence in a specific population. These studies were focused on data collection rather than methods of treating cold-induced injuries. In general, these selected studies focus on the causes and occurrence of frostbite.

Five studies collected data from patients records, while two studies utilized questionnaires (Figure 1).

The following provides a brief overview of the results of the studies. Due to variations in population characteristics, environmental factors and research methodologies employed in these studies, a wide range of frostbite injury incidences was observed.

The study of Juopperi et al. determined the incidence of frostbite and its association with gender, age, and ambient temperature in a nationwide sample.[11] They included all patients admitted to hospitals in Finland between October and May from 1986 to 1995 who had frostbite as their primary or secondary diagnosis. The data were collected from the nationwide hospital discharge register maintained by the National Research and Development Centre for Welfare and Health since 1967. A total of 1212 patients who met the study criteria were included.[11] The aim of the study by Ervasti et al. was to analyze the life-time occurrence of frostbite in young men aged 17–30 years entering military service in Finland. Data were collected using questionnaires. A total of 5839 men were asked about cold-related disturbances in the peripheral circulation, exposure to vibration, and smoking habits. The sites most prone to frostbite were the head, 1668 cases (31%), followed by the hands, 1154 (20%), and the feet, 810 (15%). The risk for frostbite in different body parts was increased among the subjects with cold-provoked white finger syndrome (CPWF) (95% CI: 1.66 to 3.87), regular smokers (95% CI: 1.02 to 3.15), and those exposed to vibration (95% CI: 1.07 to 4.03).[5] Harirchi et al. investigated the incidence of frostbite and associated factors in mountaineering, with a focus on identifying modifiable factors that could reduce its frequency and severity. Participants were mountaineers with at least two years of mountaineering experience and involved in at least two ascents per month to summits higher than 3000 m, where hypoxia also played a significant role among other frostbite risks. Data were collected using questionnaires. A total of 637 participants met the study criteria. Participants were asked to indicate the body part affected, the degree of injury, approximate altitude, season, equipment used, whether they were accompanied by a guide, and perceived causes of the injury. Lack of proper equipment and lack of a guide ($p < 0.001$) were significantly associated with frostbite. Inappropriate clothing, lack of or incorrect use of equipment, and lack of knowledge about how to deal with the cold and severe weather were identified as the main reasons for frostbite.[13]

Némethy et al. recorded all visits to the Everest Base Camp Medical Clinic to characterize the medical problems that occur in these patients including dermal trauma such as frostbite. The clinic documentation of patients attended during the initial 10 consecutive seasons (2003 to 2012) was examined. The medical staff at Everest ER attended to a total of 2941 patients, resulting in 3569 diagnoses, including dermal diagnosis including frostbite.[14] Ströhle et al. investigated the incidence of frostbite injuries in the Austrian Alps, with the intention of better prevention and treatment strategies. They included data with frostbite injuries from the National Registry of Alpine Accidents from January 1, 2005, to December 31, 2015, with frostbite injuries. A total of 31 patients' data were included.[1] The aims of the Endorf and Nygaard studies from 2021 were to investigate the incidence of amputation as a result of frostbite injury in the United States.[8,9] The data were obtained from the National Inpatient Sample from 2016 to 2018. A total of 8085 patients were included in the study.[8] In their next study from 2021, using the National Inpatient Sample (2016–2018), 7560 patients with frostbite aged 15 years and older with frostbite were included.[9]

Results

The previously presented studies demonstrate that there are varying incidences and degrees of frostbite depending on the population and their environment (Figure 2). This indicates that data comparability is compromised unless the external and internal circumstances surrounding the occurrence of cold injury are documented.

The results from Juopperi et al. showed that the overall incidence of frostbite in Finland was 2.5 per 100,000 inhabitants within a period of 10 years (1986––1995). In northern Finland the incidence was higher than in Southern and central Finland and the Helsinki area (3.9/100,000 per year to 2.8/100,000 per year). There was a higher incidence in males than females and a linear increase with age. The annual incidence of

frostbite began to rise at temperatures below −15°C and was significant at under −20°C, particularly in northern Finland. However, the daily incidence increased most in the urban area of Helsinki.11 The results from Ervasti et al. showed that the life-time and annual occurrences of frostbite were 44% and 2.2% respectively (n = 2555). 2333 subjects (41%) had suffered first-degree freezing injury and 671 (12%) suffered severe injury at some time in their lives.[5] The mean incidence of frostbite in Harirchi et al. was 366/1000 population per year, with grade 1 injuries (83.0%), and hands (26.4%) and feet (24.1%) involvement being most common.[13]

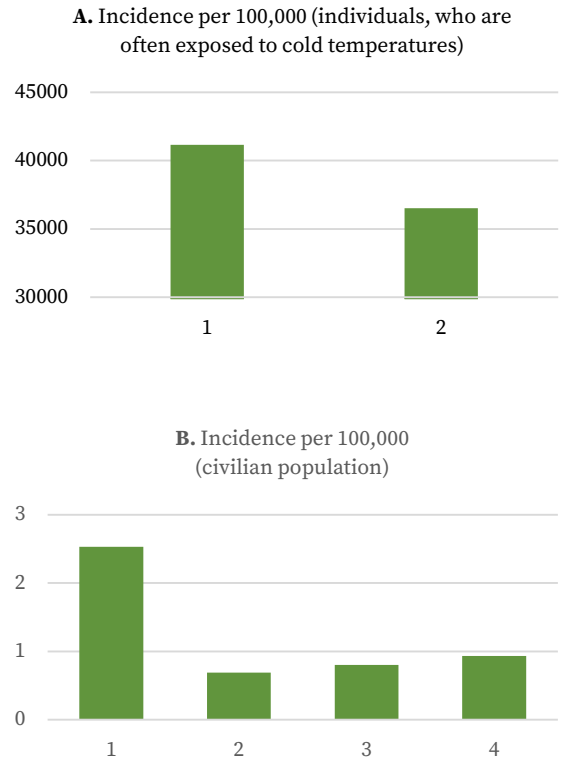

Figure 2. Frostbite incidences per 100,000 A: Individuals, who are often exposed to cold temperatures (military personnel and mountaineers); B: Civilian population

A1 shows the incidence based on Ervasti, et al. (2004);[1] A2 shows the incidence based on Harirchi, et al. (2005);[13] B1 shows the incidence based on Juopperi, et al. (2002);[11] B2 shows the incidence based on Ströhle, et al. (2018);[1] B3 shows the incidence based on Endorf and Nygaard (2021)[8] and B4 shows the incidence based on Endorf and Nygaard (2021).[9]

Némethy et al. identified a total of 280 dermatology cases, out of which 27% were attributed to frostbite injuries. This corresponds to 43 frostbite cases, resulting in an annual frostbite incidence of 0.8/100,000.[14] Ströhle et al. found an incidence of 0.07/100,000 per year. The results showed that thirty-one frostbite cases were documented nationwide, 18 (58%) of which occurred in the western states of Austria and were potentially referred to the Innsbruck Medical University Hospital. Six (19.6%) patients were female. Frostbite was almost exclusively related to fingers and toes (90% of cases).[1]

The incidence rate in Endorf and Nygaard was 0.83/100,000 per year when patients aged 15 and younger were excluded.[8] When including these patients as in the second study of Endorf and Nygaard the incidence was 0.95.[9] The results of both studies showed, among other things, that the social factors associated with frostbite injury, homelessness and black race were independently associated with a higher likelihood of amputation at the primary admission.[8,9] Cumulative data from the studies are summarized in Table 1.

Table 1. Frostbite incidence in different studies per 100,000 per year and occurrence in %. Different studies had different numbers of frostbite cases in different study populations such as civil population (CP), Military personnel (MP) or mountaineers (M)

Article	Incidence per 100,000 per year	Occurrence in %	n (Frostbite cases)	Population
Juopperi et al. (2002)[11]				
Total Finland	2.5	–		CP
Northern Finland	3.9	–	1,275	CP
Southern and central Finland	2.8	–		CP
Helsinki area	2.8	–		CP
Ervasti et al. (2004)[5]	–	44 (in life-time)	2,555	MP
	2,200	2.2	2,555	MP
Harirchi et al. (2005)[13]	36,600	36.6	467	M
Némethy et al. (2015)[14]	–	0.8	43	M
Ströhle et al. (2018)[1]	0.07	–	31	CP
Endorf and Nygaard (2021)[8]				
Total 2016–2018	0.83	–	8,085	CP
2016	–	–	2,120	CP
2017	–	–	2,025	CP
2018	–	–	3,945	CP

Article	Incidence per 100,000 per year	Occurrence in %	n (Frostbite cases)	Population
Endorf and Nygaard (2021)[9]	0.95	–	6,955	CP

Discussion

Frostbite injuries, a form of cold injury, are relatively rare but their incidence is expected to increase with the progression of climate change, where more extreme weather events can occur.

It is evident from Figure 2 that there are substantial variations in data among the studies with regard to frostbite incidence, its occurrence patterns, the overall frequency of frostbite cases, and the scale of the study populations under investigation.

The results presented here are characterized by the utilization of diverse methodologies and the collection of different data sets. The retrospectively gathered incidences, in this regard, exhibit significant variations among them. Since these seven selected studies have already demonstrated that the incidence of frostbite is a multifactorial phenomenon that cannot be easily generalized, we assumed that a larger selection of studies would only further substantiate our findings. To enhance the comprehensiveness of the results, additional studies could be considered, such as by expanding the timeframe within which the studies were published.

Additionally, there are well-established models to calculate or estimate the risk of frostbite. The oldest was made by A. Siple and F. Passel in 1945, and it was updated by Danielsson in 1996.[16] These approaches do not provide data on the incidence but allow risk estimation.

Frostbite injuries, a form of cold injury, are relatively rare but their incidence is expected to increase with the progression of climate change, when more extreme weather events can occur.

Individuals who are frequently exposed to cold environments are more likely to suffer from frostbite. For example, the incidence among mountain climbers is several times higher than in a population of all residents of an area.[13] Comparability of the incidences is not given when comparing experienced mountain climbers with suitable equipment[13] on one hand and disadvantaged individuals, such as homeless people, drug or alcohol addicts, or those suffering from psychiatric diagnosis on the other hand.[8] Also, groups of people who are involuntarily exposed to the outdoors, such as workers in a cold environment, are more likely to suffer from frostbite.[5,8,9,10]

Furthermore, factors such as the duration of cold exposure and the workload are crucial variables influencing the risk of frostbite. While prolonged exposure leads to body cooling, a relative high workload counteracts cooling for a certain duration.

Different groups of people with frostbite also occur in different regions of a country. The urban population seems to differ from a more rural population, as it has been shown that when comparing urban incidence with incidence in the northern, more rural Finland, different incidences occur.[11]

It has been shown that frostbite occurs regardless of age and gender, although some results showed a lower risk of frostbite in women.[8,9] No study has addressed the causes of the different incidences of frostbite in men and women. It is possible that frostbite injuries are due to different risk-taking behaviors between men and women. However, it could also be that there are physiological factors that account for the different incidences.

The retrospective nature of the studies poses a problem, as not all patient data may have been documented correctly. Early discharge from the hospital may result in incomplete patient records.[8,9] In addition, it is possible that not all patients with frostbite are documented if they are treated in hospitals that are not part of the dataset.[1] With mild frostbite, it is also conceivable that no treatment was performed or that treatment was performed so late that cofactors such as alcohol or drug abuse were no longer detectable if they had caused the frostbite.[9] Accurate incidences are difficult to determine without a complete dataset or registries. Further inaccuracies in data collection and thus in the correct representation of incidences can arise from the use of questionnaires, as these are filled out by participants themselves based on their memories.[13] Even though painful experiences are better remembered than others, errors can occur, which make it more difficult to predict incidences with certainty.

Registries could document both the occurrence of frostbite and consider the external circumstances, such as the temperature at which the freezing injury occurred and the duration of cold exposure experienced by the patient. Additionally, weather conditions, including wind chill, precipitation, humidity and cloud cover, could also be taken into account. In cases where frostbite occurs in individuals under the same external conditions, it is crucial to ascertain with what, if any, protective equipment the patients used to safeguarded against the cold. If external circumstances are consistent, it becomes necessary to investigate individual

differences in susceptibility to cold and determine whether some individuals are more prone to experiencing frostbite than others.

Thus, reliable data is lacking to enable predictability of frostbite worldwide. According to recent studies from Gorjanc et al. dealing with frostbite susceptibility, frostbite incidence could sometimes be reduced by positive selection of participants in predicted outdoor activities in the cold. Additionally, in their study, some alpinists seemed to be more prone to frostbite injury, and this susceptibility can be measured or at least estimated with a simple cold water immersion test.[12,15] In estimating frostbite susceptibility in high-risk groups, the incidence of frostbite could be reduced, at least in populations more often exposed to cold, such as mountaineers and military personnel. This could contribute to better prevention measures, such as cold-resistant clothing, better protective measures, or providing a higher concentration of homeless shelters in cold environments.[10,12]

Limitations of the study

Undoubtedly, this narrative, rather than systematic, review is subject to several constraining factors. Among these are the divergent methodologies employed in the studies utilized for the review, posing challenges to the comparability of the data. While one set of investigations employed patient survey questionnaires,[5,13] others drew upon national patient data registries for analysis. Beyond the diversity in data collection methods, the scale of the study populations must also be taken into account. Studied population sizes varied widely, ranging from 31 to 42,810 patients. The notably small study populations may potentially lead to data imprecision.

Moreover, the relatively modest number of studies incorporated into this review is an additional potential source of inaccuracies. The limited volume of available research could introduce an element of bias or incomplete representation.

Furthermore, dissimilar geographical regions and varying environmental conditions could potentially impede full data comparability. The incidence of frostbite might be influenced differentially by the diverse environmental factors encountered across these studies.

In summary, these constraints underline the need for cautious interpretation of the findings presented in this review. The variances in methodologies, study population sizes, and contextual factors remind us of the intricate nature of such analyses and the importance of addressing these limitations in the overall understanding of the topic.

Conclusions

General frostbite incidence of a population is difficult to define. Frostbite incidences of the included studies are insufficiently comparable to draw any conclusions on possible general frostbite incidence in a population. To enhance our ability to estimate or predict frostbite occurrences within the general population, establishing international or national frostbite registries in high-risk countries could be helpful.

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